

## COLLEGE OF ENGINEERING

Ioannis “John” Papapolymerou, INTERIM DEAN

The College of Engineering prepares its students to solve technical, social, economic, and global problems while instilling the essence of engineering — the iterative, collaborative, creative process of designing, predicting performance, building, and testing. Our programs provide future engineers with deep knowledge and understanding of engineering fundamentals, methods for application of this knowledge, and the project management and communications skills needed to bring designs to fruition. An MSU engineering education provides a team-based, systems approach to solving societal problems and prepares students for a wide range of engineering career options — and also many career paths outside of engineering.

### UNDERGRADUATE PROGRAMS

Bachelor of science degrees may be earned in applied engineering sciences, biosystems engineering, chemical engineering, civil engineering, computational data science, computer engineering, computer science, electrical engineering, environmental engineering, materials science and engineering, mechanical engineering, and technology engineering.

#### Education Abroad

Solving modern engineering challenges requires a global perspective. Education abroad provides unparalleled cultural learning experiences that can strengthen academic goals, and meet degree requirements, while providing opportunities for students to study in a variety of countries. Students interested in education abroad should contact their engineering academic advisor.

#### Minors

Students who are enrolled in bachelor's degree programs in the college may elect the Minor in Environmental and Sustainability Studies. For additional information, refer to the statement on *Minor in Environmental and Sustainability Studies* in the *College of Natural Science* section of this catalog.

Students who are enrolled in bachelor's degree programs in The Eli Broad College of Business, the College of Communication Arts and Sciences, and the College of Engineering may elect a Minor in Information Technology. For additional information, refer to the statement on *Minor in Information Technology* in *The Eli Broad College of Business* section of this catalog or contact The Eli Broad College of Business.

Students who are enrolled in the Bachelor of Science degree in Computer Science in the College of Engineering may elect a Minor in Game Design and Development. For additional information, refer to the statement on *Minor in Game Design and Development* in the *Department of Media and Information* section of this catalog.

#### Experiential Education

The College of Engineering helps students gain real-world experience in engineering. Opportunities include cooperative

education, engineering internships, and undergraduate research. Cooperative education is a program of alternating full-time employment in industry and full-time study on campus. Engineering internships are usually individual, career-based experiences often completed during the summer. Students who are considering graduate school are encouraged to participate in undergraduate research for exposure to state-of-the-art research areas and to gain insight about the differences between undergraduate and graduate study.

#### The CoRe Experience

The CoRe Experience living-learning program integrates first-year engineering academics and co-curricular/residential activities to support the academic, professional, and personal growth of engineering students during their first year at MSU.

#### Supportive Services

The college provides a full range of supportive services including professional academic advising, tutoring, services for underrepresented and female students, career guidance and employment assistance, faculty connections, and peer mentors.

#### Admission to the College

Admission to the College of Engineering and a specific major provides access to enroll in certain courses required for the major. Enrollments in the College of Engineering are limited. Admission is based on the cumulative grade-point average of all courses taken and a grade-point average calculated on mathematics, physical and biological sciences, and engineering courses.

For additional information, students should contact the Undergraduate Studies Office in the College of Engineering.

Minimum criteria for admission to all programs except Technology Engineering are:

1. Completion of at least 28 credits earned after matriculation to Michigan State University.
2. Completion of Mathematics 132 and 133 with a minimum grade of 2.0 in each course.
3. A minimum grade-point average of 2.0 in all mathematics courses.
4. Completion of Chemistry 141 or 151 or approved substitution or waiver. Biosystems Engineering, Chemical Engineering and Materials Science and Engineering require CEM 151. Computational Data Science and Computer Science majors are not required to fulfill this requirement.
5. Completion of Physics 183.
6. Completion of Engineering 102 or Computer Science and Engineering 231 or Computer Science and Engineering 220 Computational Mathematics, Science and Engineering 202 or approved substitution or waiver.
7. Completion of Engineering 100.

Minimum criteria for admission to the Technology Engineering program:

1. Completion of at least 28 credits earned after matriculation to Michigan State University.

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2. Completion of Mathematics 116 and 132 with a minimum grade of 2.0 in each course.
3. A minimum grade-point average of 2.0 in all mathematics courses.
4. Completion of Chemistry 141 or 151 or approved substitution or waiver.
5. Completion of Physics 183 or 231.
6. Completion of Engineering 102 or Computer Science 231.
7. Completion of Engineering 100.

Students interested in applying for a degree granting major in the College of Engineering may apply for admission during each semester, and applications will be reviewed after the end of each semester. Students must be admitted to a degree-granting college at the time they have completed 56 credits. Students must be admitted to a degree-granting college at the time they have completed 56 credits.

### **Admission to a Second Bachelor's Degree Program**

Students seeking admission to a second bachelor's degree program must meet the same requirements as for admission to the college.

### **Graduation Requirements for All Majors**

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of the catalog; 120 credits, including general elective credits, are required for the Bachelor of Science degree in Computational Data Science, Bachelor of Science degree in Computer Science and the Bachelor of Science degree in Applied Engineering Sciences; and 128 credits, including general elective credits, are required for the Bachelor of Science degree in the other Engineering majors.

Students who are enrolled in majors leading to the Bachelor of Science degree in the College of Engineering may complete an alternative track to Integrative Studies in Biological and Physical Sciences that consists of the following courses:

- a. One of the following courses: Biological Science 161; Plant Biology 105; Entomology 205; Integrative Biology 150; Microbiology and Molecular Genetics 141, 201, 301; Physiology 250.
  - b. Two of the following courses: Chemistry 141, Chemistry 151, Physics 183 or 183B, Physics 184 or 184B. Technology Engineering majors may use Physics 231 or 232.
  - c. One of the following laboratory courses: Plant Biology 106; Chemistry 161; Physics 191. Technology Engineering majors may use Physics 251.
- Credits earned in the alternative track may also be counted toward college and major requirements for the Bachelor of Science degree.
2. The requirements of the College of Engineering for the Bachelor of Science degree in all majors other than Technology Engineering that are listed below:

- a. Mathematics 132, 133, 234, and 235. Computational Data Science and Computer Science majors are not required to complete Mathematics 235.
  - b. Chemistry 141 or 151. Biosystems Engineering, Chemical Engineering and Materials Science and Engineering require CEM 151. Computational Data Science and Computer Science majors are not required to complete Chemistry 141 or 151.
  - c. Physics 183 or 183B and 184 or 184B.
  - d. Engineering 100.
  - e. One technical computing course depending on intended major: CMSE 202 (Computational Data Science), CSE 220 (Electrical Engineering), CSE 231 (Computer Science, Computer Engineering, Mechanical Engineering) or EGR 102 (all other Engineering majors).
3. The requirements of the College of Engineering for the Bachelor of Science degree in Technology Engineering that are listed below:
    - a. Mathematics 116 and 132.
    - b. Chemistry 141 or 151.
    - c. Physics 183 or 183B or 231 and 184 or 184B or 232.
    - d. Engineering 100.
    - e. Engineering 102.
    - f. Computer Science and Engineering 231.

Students who are enrolled in bachelor's degree programs in the College of Engineering may elect a Minor in Environmental and Sustainability Studies. For additional information, refer to the *Minor in Environmental and Sustainability Studies* statement in the *College of Natural Science* section of this catalog.

Students who are enrolled in the Bachelor of Science Degree in Computer Science in the College of Engineering may elect a Minor in Game Design and Development. For additional information, refer to the *Minor in Game Design and Development* statement in the *Department of Media and Information* section of this catalog.

Students who are enrolled in bachelor's degree programs in the College of Engineering may elect a Minor in Information Technology. For additional information, refer to the *Minor in Information Technology* statement in *The Eli Broad College of Business* section of this catalog.

## **APPLIED ENGINEERING SCIENCES**

The Applied Engineering Sciences major provides undergraduate opportunities leading to the Bachelor of Science degree. The core goal of applied engineering sciences is to prepare technically competent, broad-based engineering graduates who have acquired a systems perspective for problem-solving and business expertise. The program provides a broad foundation in science and mathematics, engineering, and business management and is designed to develop graduates who can apply the rigor of their technical education to diverse problems and settings. The program is structured to establish skills in areas such as effective management, contemporary technical issues, deployment of new technologies, resolving ethical dilemmas, effective communication across technical disciplines both in oral and written communication, and lifelong learning.

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### Requirements for the Bachelor of Science Degree in Applied Engineering Sciences

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 120 credits, including general elective credits, are required for the Bachelor of Science degree in Applied Engineering Sciences.

Students who select the Business Analytics concentration will be required to complete 133 credits for the degree.

The University's Tier II writing requirement for the Applied Engineering Sciences major is met by completing Applied Engineering Sciences 410. That course is referenced in item 3. a. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

a. All of the following courses (41 credits):

ACC	230	Survey of Accounting Concepts	3
AESC	110	AES as a Profession	1
AESC	210	Global Systems: Economics, Engineering, Environment	3
AESC	310	Sustainable Systems Analysis	3
AESC	410	Capstone Project in Applied Engineering Sciences	3
CE	221	Statics	3
CEM	161	Chemistry Laboratory I	1
EC	201	Introduction to Microeconomics	3
EC	202	Introduction to Macroeconomics	3
ECE	345	Electronic Instrumentation and Systems	3
ENE	371	Sustainable Civil and Environmental Engineering Systems	3
ME	201	Thermodynamics	3
ME	280	Graphic Communications	2
MKT	317	Market Analytics	3
MSE	250	Materials Science and Engineering	3
PHY	191	Physics Laboratory for Scientists, I	1

b. One of the following courses (3 credits):

COM	225	An Introduction to Interpersonal Communication	3
MGT	325	Management Skills and Processes	3

c. One of the following courses (3 or 4 credits):

STT	351	Probability and Statistics for Engineering	3
STT	380	Probability and Statistics for Data Science	4

d. **Concentration:** 15 to 38

In consultation with their academic advisor, students must select one of the following concentrations: business law, computer science, packaging, supply chain management, or technical sales. For students interested in computer science, the minimum criteria for acceptance is the completion of Computer Science and Engineering 231 and 260 with a combined grade-point average in those two courses of 3.0. The concentration will be noted on the student's academic record.

#### **Business Analytics** (38 credits)

1. All of the following courses (15 credits):

EC	301	Intermediate Microeconomics	3
FI	320	Introduction to Finance	3
GBL	385	Business Law and Ethical Leadership	3
MKT	327	Introduction to Marketing	3
SCM	303	Introduction to Supply Chain Management	3

2. Completion of the Minor in Data Science 23

#### **Business Law** (15 or 16 credits)

1. All of the following courses (12 credits):

EC	301	Intermediate Microeconomics	3
EC	425	Law and Economics (W)	3
GBL	385	Business Law and Ethical Leadership	3
GBL	480	Environmental Law and Sustainability for Business: From Local to Global	3

2. One of the following courses (3 or 4 credits):

PHL	345	Business Ethics	4
PHL	354	Philosophy of Law	3
PLS	320	Judicial Politics	3
PLS	321	Constitutional Law	3

PLS 322 Comparative Legal Systems 3

#### **Computer Science** (18 or 19 credits)

1. All of the following courses (12 credits):

CSE	231	Introduction to Programming I	4
CSE	232	Introduction to Programming II	4
CSE	260	Discrete Structures in Computer Science	4

2. Two of the following courses (6 or 7 credits):

CSE	320	Computer Organization and Architecture	3
CSE	325	Computer Systems	3
CSE	331	Algorithms and Data Structures	3
CSE	335	Object-oriented Software Design	4
CSE	380	Information Management and the Cloud	3
CSE	420	Computer Architecture	3
CSE	429	Interdisciplinary Topics in CyberSecurity	3
CSE	431	Algorithm Engineering	3
CSE	476	Mobile Application Development	3
CSE	477	Web Application Architecture and Development	3
CSE	480	Database Systems	3

#### **Packaging** (17 credits):

All of the following courses:

CEM	143	Survey of Organic Chemistry	4
PKG	101	Principles of Packaging	3
PKG	221	Packaging with Glass and Metal	2
PKG	322	Packaging with Paper and Paperboard	4
PKG	323	Packaging with Plastics	4

#### **Supply Chain Management** (15 credits)

All of the following courses:

FI	320	Introduction to Finance	3
MKT	327	Introduction to Marketing	3
SCM	303	Introduction to Supply Chain Management	3
SCM	371	Procurement and Supply Management	3
SCM	372	Manufacturing and Service Operations Management	3

#### **Technical Sales** (18 credits)

All of the following courses:

COM	360	Advanced Sales Communication	3
COM	483	Practicum in Sales Communication	1
FI	320	Introduction to Finance	3
MGT	474	Negotiations	2
MKT	313	Consultative Selling	3
MKT	327	Introduction to Marketing	3
MKT	383	Sales Management	3

## TECHNOLOGY ENGINEERING

### *Bachelor of Science*

The Bachelor of Science degree in Technology Engineering is an innovative program which prepares students for modern engineering challenges in the multidisciplinary, interconnected world. The degree is designed to develop engineering and technology foundational skills including, but not limited to, embedded electronic systems, computer aided design, product prototyping, data science, project management, and computer programming in Python and C++. Students will choose a concentration in Mechatronics or Embedded Cybersecurity, to further advance their engineering and technology interests. The program utilizes hands-on, real-world projects to integrate modern technologies with the engineering mindset.

### Requirements for the Bachelor of Science Degree in Technology Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Technology Engineering.

The University's Tier II writing requirement for the Technology Engineering major is met by completing Technology Engineering 480. That course is

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referenced in item 3. b. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the College statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

	CREDITS
a. All of the following courses (26 credits):	
CEM 161 General Chemistry Laboratory I	1
CSE 232 Introduction to Programming II	4
ECE 230 Digital Logic Fundamentals	3
ME 280 Graphic Communications	2
MGT 325 Management Skills and Processes	3
Or	
SCM 304 Survey of Supply Chain Management	3
MSE 250 Materials Science and Engineering	3
PHY 251 Introductory Physics Laboratory I	1
Or	
PHY 191 Physics Laboratory for Scientists I	1
PHY 252 Introductory Physics Laboratory II	1
STT 180 Introduction to Data Science	4
STT 201 Statistical Methods	4
b. One of the following courses (3 or 4 credits):	
BS 161 Cell and Molecular Biology	3
CEM 142 General and Inorganic Chemistry	3
CEM 143 Survey of Organic Chemistry	4
CEM 144 Organic Chemistry and Applications	3
CEM 152 Principles of Chemistry	3
ENT 205 Pests, Society and Environment	3
IBIO 150 Integrating Biology: From DNA to Populations	3
MGI 141 Introductory Human Genetics	3
MGI 201 Fundamentals of Microbiology	3
PLB 105 Plant Biology	3
PSL 250 Introductory Physiology	4
MTH 133 Calculus II	4
MTH 299 Transitions	4
Students cannot fulfill both the math/basic science elective and the University Bioscience requirement with the same course.	
c. All of the following courses (25 credits):	
TNG 210 Manufacturing Processes and Prototyping	2
TNG 220 Electrical Circuits	4
TNG 310 Advanced Graphics Communications	3
TNG 320 Sensors and Signal Processing	3
TNG 322 Electronics and Embedded Systems Lab	1
TNG 330 Quality and Continuous Improvement	3
TNG 335 Computer Security Fundamentals	3
TNG 430 Engineering Project Management	3
TNG 480 Technology Engineering Capstone (W)	3
d. In consultation with their academic advisor, students must select one of following: Embedded Cybersecurity concentration or Mechatronics concentration or the Smart Agricultural Systems minor. The concentration or minor will be noted on the student's academic record. (16 credits):	
<b>Mechatronics</b>	
TNG 340 Engineering Statics and Mechanics of Materials	3
TNG 345 Mechanical Machine Dynamics	3
TNG 440 Robotics, Automation, and Controls	3
TNG 445 Troubleshooting Mechatronic Systems	4
TNG 447 Topics in Mechatronics	3
<b>Embedded Cybersecurity</b>	
TNG 350 Operating System Fundamentals	3
TNG 355 Networks and Network Security	3
TNG 450 Hardware Cybersecurity	3
TNG 455 Engineering Secure Hardware and Software	4
TNG 457 Topics in Embedded Cybersecurity	3
The concentration will be noted on the student's academic record.	
<b>Smart Agricultural Systems Minor</b>	
Students must complete a minimum of 16 credits from the following:	
1. All of the following courses (10 credits):	
BE 221 Introduction to Smart Agriculture	1

BE 321 Principles of Precision Agriculture	3
BE 421 Sensors and Robotics for Agricultural Systems	3
BE 422 Crop Modeling and Optimization	3
2. Two of the following courses (6 or 7 credits):	
BE 449 Human Health Risk Analysis for Engineering Controls	3
BE 456 Electric Power and Control	3
BE 481 Water Resources Systems Analysis and Modeling	3
BE 482 Engineering Ecological Treatment Systems	3
CSE 404 Introduction to Machine Learning	3
CSE 440 Introduction to Artificial Intelligence	3
CSE 480 Database Systems	3
CSE 482 Big Data Analysis	3
CSS 467 Bioenergy Feedstock Production	3
ECE 416 Digital Control	4
ECE 417 Robotics	4
ECE 431 Smart Sensor Systems	3
ECE 434 Autonomous Vehicles	3
ECE 477 Microelectronic Fabrication	3
ME 417 Design of Alternative Energy Systems	3
ME 451 Control Systems	4
ME 456 Mechatronic System Design	3

### MINOR IN ENERGY

The Minor in Energy, administered by the College of Engineering, provides students with a foundation in energy science that focuses on topics of fundamental physical principles guiding energy generation, utilization, conservation, engineering applications and the impact of energy within a societal and geological context. Students gain a perspective in energy science that is applicable to many disciplines and highly interdisciplinary. It offers opportunities for students to prepare to work in industry, research, or government, as well as preparation for graduate studies in energy science.

The minor is available as an elective to students who are enrolled in bachelor's degree programs in the College of Engineering. With the approval of the department and college that administer the student's degree program, the courses that are used to satisfy the minor may also be used to satisfy the requirements for the bachelor's degree. At least 9 credits counted towards the requirements for this minor must be unique. Unique credits must not be used to fulfill another university, college, or major requirement in the student's program.

Students who plan to complete the requirements of the minor should consult the undergraduate advisor in the College of Engineering. Students accepted into the minor must be admitted to the College of Engineering and have completed items 1. and 2. of the requirements stated below. Enrollment for some courses may not be available and may be limited. Application forms are available at <https://www.egr.msu.edu/form/application-form-minor-energy>.

### Requirements for the Minor in Energy

Complete a minimum of 21 credits from the following.

	CREDITS
1. One of the following courses (3 credits):	
BE 230 Engineering Analysis of Biological Systems	3
CHE 201 Material and Energy Balances	3
MSE 250 Materials Science and Engineering	3
2. One of the following courses (3 or 4 credits):	
BE 351 Thermodynamics for Biological Engineering	3
CHE 321 Thermodynamics for Chemical Engineering	4
ECE 320 Energy Conversion and Power Electronics	3

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ME 201	Thermodynamics	3
MSE 310	Phase Equilibria in Materials	3
3.	One of the following courses (3 credits):	
BE 456	Electric Power and Control	3
ECE 302	Electronic Circuits	3
ECE 345	Electronic Instrumentation and Systems	3
4.	One of the following courses (3 credits):	
CE 473	Smart and Sustainable Building Design and Operations	3
ENE 472	Life Cycle Assessment of Energy Technologies	3
ME 417	Design of Alternative Energy Systems	3
MSE 410	Materials Foundations for Energy Applications	3
5.	One of the following courses (3 credits):	
AESC 310	Sustainable Systems Analysis	3
AFRE 265	Ecological Economics	3
CE 371	Sustainable Civil and Environmental Engineering Systems	3
CSUS 200	Introduction to Sustainability	3
6.	Two of the following courses (6 to 8 credits):	
AFRE 360	Environmental Economics	3
AFRE 829	Economics of Environmental Resources	3
BE 469	Sustainable Bioenergy Systems	3
CE 473	Smart and Sustainable Building Design and Operations	3
CEM 485	Modern Nuclear Chemistry	3
CHE 468	Biomass Conversion Engineering	3
CSS 467	BioEnergy Feedstock Production	3
CSUS 200	Introduction Sustainability	3
CSUS 259	Sustainable Energy and Society	3
CSUS 491	Special Topics in Community Sustainability	1 to 3
ECE 423	Power System Analysis	3
ECE 425	Solid State Power Conversion	3
ECE 476	Electro-Optics	4
ECE 821	Advanced Power Electronics and Applications	3
ENE 472	Life Cycle Assessment of Energy Technologies	3
ENE 489	Air Pollution: Science and Engineering	3
FOR 414	Renewable Wood Products	3
GLG 201	Introduction to Earth and Planetary Sciences	4
GLG 203	Geology of the Great Lakes Region	3
GLG 471	Applied Geophysics	4
MC 450	International Environmental Law and Policy	3
ME 417	Design of Alternative Energy Systems	3
ME 422	Introduction to Combustion	3
ME 442	Turbomachinery	3
ME 444	Automotive Engines	3
MSE 410	Materials Foundations for Energy Applications	3
MSE 460	Electronic Structure and Bonding in Materials and Devices	3
TSM 130	Energy Efficiency and Conservation in Agricultural Systems	3

A course used to fulfill requirement 4. or 5. above may not be used to fulfill requirement 6. Not all courses will be available to all majors and students must meet all course prerequisites and restrictions.

## GRADUATE STUDY

The College of Engineering offers programs leading to the Master of Science and Doctor of Philosophy degrees in biomedical engineering; chemical engineering; civil engineering; computational mathematics, science and engineering; computer science; electrical engineering; engineering mechanics; environmental engineering; materials science and engineering; and mechanical engineering. Programs leading to the Master of Science and Doctor of Philosophy degrees in biosystems engineering are offered through the College of Agriculture and Natural Resources.

Graduate programs in the College of Engineering prepare graduates to be leaders in research and development, whether in industry, academia, or a research institution.

## Master of Science

In addition to meeting the requirements of the University as described in the Graduate Education section of this catalog, students must meet the requirements specified below.

### Admission

**Regular Status.** Admission to a master's degree program with regular status may be granted by the department, subject to the availability of resources and to the approval of the dean, upon consideration of the likelihood that the applicant will be able to pursue a master's program successfully without taking collateral courses. As evidence of eligibility for admission, the student may offer any of the following:

- The possession of a bachelor's degree in an accredited program in engineering with a grade-point average not lower than 3.00 for the final two years of the undergraduate program, or with standing in the upper quarter of the graduating class in the student's major.
- The possession of a bachelor's degree in engineering or a related field where the applicant has shown very high academic achievement, as certified by the department.
- Evidence of ability and resolution to complete a master's program, as attested by the department upon review of the applicant's academic record, test scores, experience, reference statements, professional qualifications, proposed studies, and other relevant information.

**Provisional Status.** Admission to a master's degree program with provisional status may be granted by the department, subject to the approval of the dean:

- To an applicant qualified for regular admission except that collateral courses are deemed necessary, or
- To an applicant whose record is incomplete.

If collateral courses are required, the minimum acceptable grades and the semesters by which those courses must be completed will be specified on the admission form. The provisional status will be changed to regular status when the conditions specified on the admission form have been met, as certified by the department and approved by the dean.

## Program Filing

The student's program of study must be approved before the student completes 6 credits of graduate work in order for the student to continue to enroll in the master's degree program. For any independent study or selected topics course that is included in the student's approved program of study, the subject material and the instructor must be specified.

## Modification of Program

With reference to the student's approved program of study, none of the following types of changes will be approved:

- Adding or deleting a course for which a grade has already been assigned under any of the three grading systems (numerical, Pass–No Grade, or Credit–No Credit).
- Adding or deleting a course for which grading was postponed by the use of the DF–Deferred marker.

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3. Adding or deleting a course which the student dropped after the middle of the semester and for which "W" or "N" or "0.0" was designated.
4. Adding or deleting a course during the final semester of enrollment in the master's degree program.

### Requirements for the Master of Science Degree

The student must:

1. Complete a minimum of 30 credits in 400-, 800-, and 900-level courses under either Plan A (with thesis) or Plan B (without thesis). Courses below the 400 level may not be counted toward the requirements for the degree.
  - a. **Requirements for Plan A:** The student must:
    - (1) Complete a minimum of 20 credits in courses at the 800–900 level.
    - (2) Complete at least 4, but not more than 8, credits in Master's Thesis Research (course number 899 in the department of the student's major).
    - (3) Provide to the major professor and to the department a hard-bound copy of the thesis made from the original unbound manuscript submitted to the Office of The Graduate School. Arrangements for delivery of the copies shall be made when the original manuscript is submitted to the Office of The Graduate School.
  - b. **Requirements for Plan B:** The student must:
    - (1) Complete a minimum of 18 credits in courses at the 800–900 level.
2. Pass the final certifying examination administered by the student's department. It is the student's responsibility to obtain detailed information about this examination from the department.

### Academic Standards

1. **Grades.** The student must earn a grade of 2.0 or higher in each course in the approved program of study. The student must repeat any course for which the grade earned was below 2.0.
2. **Cumulative Grade-Point Average.** The student must maintain a cumulative grade-point average of at least 3.00 in the courses in the approved program of study.
3. **Probational Status.** A student is placed on probational status if the student's cumulative grade-point average for the courses in the approved program of study is below 3.00. A student in probational status is not allowed to carry more than 7 credits per semester or to enroll in any course the primary focus of which is independent study.
4. **Retention In and Dismissal From the Program.**
  - a. **Cumulative Grade-Point Average.** Should a student's cumulative grade-point average fall below 3.00 after having completed 16 or more credits in courses in the approved program of study, the student may be enrolled in probational status in the master's degree program for one additional semester. If at the end of the additional semester the student's cumulative grade-point average is 3.00 or higher, the student may continue to enroll in the

master's degree program. If at the end of the additional semester the student's cumulative grade-point average is still below 3.00, the student will be dismissed from the program.

- b. **Academic Progress and Professional Potential.** Each student's academic progress and professional potential are evaluated by March 15 of each year. A student who in the judgment of the faculty is making satisfactory academic progress and has professional potential may continue to enroll in the master's degree program. A student who in the judgment of the faculty is not making satisfactory academic progress or lacks professional potential will be dismissed from the program.

### Transfer Credits

As a member of the Michigan Coalition for Engineering Education (MCEE), Michigan State University will accept up to one less than half of the course credits required for the Master of Science degree program in the College of Engineering in transfer from other MCEE member institutions provided that (1) the student earned a grade of at least 3.0, or the equivalent, in the related courses; (2) the credits were not earned in research or thesis courses; and (3) the total number of credits accepted in transfer from MCEE member institutions and from other institutions does not exceed one less than half of the credits required.

### Doctor of Philosophy

In addition to meeting the requirements of the university as described in the Graduate Education section of this catalog, students must meet the requirements specified below.

### Admission

**Regular Status.** Admission to a doctoral degree program with regular status may be granted by the department, subject to the availability of resources and to the approval of the dean, upon consideration of the likelihood that the applicant will be able to pursue a doctoral program successfully without taking collateral courses. As evidence of eligibility for admission, the student may offer any of the following:

- a. The possession of a master's degree in engineering or a related field.
- b. The completion of the equivalent of a master's degree program in the major field.
- c. Evidence of ability and resolution to complete a doctoral program, as attested by the department upon review of the applicant's academic record, test scores, experience, reference statements, professional qualifications, proposed studies, and other relevant information.

Admission to the doctoral program without a master's degree, or the equivalent thereof, will require special consideration by the department and the dean.

**Provisional Status.** Admission to a doctoral degree program with provisional status may be granted by the department, subject to the approval of the dean:

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- a. To an applicant qualified for regular admission except that collateral courses are deemed necessary, or
- b. To an applicant whose record is incomplete.

If collateral courses are required, the minimum acceptable grades and the semesters by which those courses must be completed will be specified on the admission form. The provisional status will be changed to regular status when the conditions specified on the admission form have been met, as determined by the department and approved by the dean.

### Guidance Committee

The student's guidance committee is appointed by the department chairperson in consultation with the student and the appropriate faculty members, and with the approval of the dean. At least two members of the guidance committee shall be from the major department and at least one member shall be from a department outside of the major department. The chairperson of the guidance committee will be appointed by the department chairperson after consultation with the student and the person recommended to chair the committee.

### Guidance Committee Report

The student's program of study shall be submitted for approval to the department and to the Dean by no later than the end of the student's second semester of enrollment in the doctoral program. For any independent study or selected topics course that is included in the student's program of study, the subject material and the instructor must be specified.

The student's program of study must be approved in order for the student to continue to enroll in the doctoral degree program beyond the second semester.

### Modification of Program

With reference to the student's approved guidance committee report, none of the following types of changes will be approved:

1. Adding or deleting a course for which a grade has already been assigned under any of the three grading systems (numerical, Pass–No Grade, or Credit–No Credit).
2. Adding or deleting a course for which grading was postponed by the use of the DF–Deferred marker.
3. Adding or deleting a course which the student dropped after the middle of the semester and for which “W” or “N” or “0.0” was designated.
4. Adding or deleting a course during the final semester of enrollment in the doctoral degree program.

### Requirements for the Doctor of Philosophy Degree

The student must:

1. Pass the qualifying examination administered by the student's department. It is the student's responsibility to obtain detailed information about this examination from the department.
2. Pass the doctoral comprehensive examination at least six months prior to the final oral examination in defense of the dissertation. The examination may be retaken no more than twice. It is the student's responsibility to obtain

detailed information about this examination from the department.

3. Provide to the major professor and to the department a hard-bound copy of the dissertation made from the original unbound manuscript submitted to the Office of the Graduate School. Arrangements for delivery of the copies shall be made when the original manuscript is submitted to the Office of The Graduate School.

### Academic Standards

1. **Grades.** The student must earn a grade of 2.0 or higher in each course in the approved guidance committee report, including collateral courses and courses accepted in transfer. The student must repeat any course for which the grade earned was below 2.0.
2. **Cumulative Grade–Point Average.** The student must maintain a cumulative grade–point average of at least 3.00 in courses in the approved guidance committee report, with the exception of collateral courses and courses accepted in transfer.
3. **Deferred Grades.** A student may accumulate no more than 3 deferred grades (identified by the DF–Deferred marker) in courses other than those courses the primary focus of which is independent study.
4. **Probational Status.** A student is placed on probational status if either or both of the following conditions apply:
  - a. The student's cumulative grade–point average for the courses in the approved guidance committee report is below 3.00.
  - b. The student has accumulated more than three deferred grades (identified by the DF–Deferred marker) in courses other than those courses the primary focus of which is independent study.A student in probational status is not allowed to carry more than 7 credits per semester or to enroll in any course the primary focus of which is independent study.
5. **Retention In and Dismissal From the Program.**
  - a. **Cumulative Grade–point Average.** Should a student's cumulative grade–point average fall below 3.00 after having completed half of the courses in the approved guidance committee report, the student may be enrolled in probational status in the doctoral degree program for one additional semester. If at the end of the additional semester the student's cumulative grade–point average is 3.00 or higher, the student may continue to enroll in the doctoral degree program. If at the end of the additional semester the student's cumulative grade–point average is still below 3.00, the student will be dismissed from the program.
  - b. **Deferred Grades.** Should a student accumulate more than 3 deferred grades (identified by the DF–Deferred marker) in courses other than those courses the primary focus of which is independent study, the student may be enrolled on probational status in the doctoral degree program for one additional semester. If at the end of the additional semester the student has no more than 3 deferred grades, the student may continue to enroll in the doctoral degree program. If at the end of the additional semester the student still has more than 3

## COLLEGE OF ENGINEERING

deferred grades, the student will be dismissed from the program.

- c. **Academic Progress and Professional Potential.** Each student's academic progress and professional potential are evaluated by March 15 of each year. A student who in the judgment of the faculty is making satisfactory academic progress and has professional potential may continue to enroll in the doctoral degree program. A student who in the judgment of the faculty is not making satisfactory academic progress or lacks professional potential will be dismissed from the program.

### **GRADUATE SPECIALIZATION IN ENVIRONMENTAL TOXICOLOGY**

The College of Engineering, the College of Agriculture and Natural Resources, the College of Natural Science, and the College of Veterinary Medicine administer the Graduate Specialization in Environmental Toxicology. The College of Agriculture and Natural Resources is the primary administrative unit. For additional information, refer to the *Graduate Specialization in Environmental Toxicology* statement in the *College of Agriculture and Natural Resources* section of this catalog.

## DEPARTMENT of BIOMEDICAL ENGINEERING

### **Adam Alessio, Chairperson**

The mission of the Department of Biomedical Engineering is to train young investigators in quantitative analyses, engineering principles and innovative design concepts for the purpose of using these approaches to create novel solutions to the most pressing healthcare needs. These approaches are used to drive the principles of precision health by enabling predictive analytics, real time monitoring, early diagnosis, rapid intervention, and quantitative measures of outcome from basic science to practical application with an overarching goal to improve human health.

### **GRADUATE STUDY**

#### **BIOMEDICAL ENGINEERING**

The Master of Science Degree in Biomedical Engineering prepares graduates to review technical literature related to a biomedical engineering research problem and communicate those results through oral presentations and written publications.

#### **Master of Science**

In addition to meeting the requirements of the university, and of the College of Engineering, students must meet the requirements specified below.

### **Admission**

For admission to the master's degree in biomedical engineering on regular status, the student must:

1. have a bachelor's degree in biomedical engineering or related field;
2. have a grade-point average that would indicate success in graduate study.

Applicants who are admitted without a bachelor's degree in biomedical engineering may be required to complete collateral course work to make up deficiencies. Collateral course work will not count towards the fulfillment of degree requirements. International applicants are required to submit their scores on the Graduate Record Examination (GRE).

### **Requirements for the Master of Science Degree in Biomedical Engineering**

The master's degree program in biomedical engineering is available under either Plan A (with thesis) or Plan B (without thesis). A total of 30 credits is required for the degree. The student's program of study is selected in consultation with a faculty advisor and the graduate program director. No more than 6 credits of 400-level courses may be counted towards the degree requirements.

	CREDITS
Student's must complete the following core course:	
BME 803 Research Methods	3

#### **Additional Requirements for Plan A**

1. Completion of the following course:  
BME 892 Biomedical Engineering Seminar 1
2. Complete of at least 4, but not more than 8, credits of BME 899 Master's Thesis Research.
3. Pass a final oral examination in defense of the thesis.

#### **Additional Requirements for Plan B**

1. Pass a final examination or evaluation.

### **Doctor of Philosophy**

The Doctor of Philosophy degree in Biomedical Engineering prepares graduates to review technical literature related to a biomedical engineering research problem and communicate those results through oral presentations and written publications.

In addition to meeting the requirements of the university, and of the College of Engineering, students must meet the requirements specified below.

### **Admission**

For admission to the doctoral degree in biomedical engineering on regular status, the student must:

1. have a bachelor's degree in biomedical engineering or related field;
2. have a grade-point average that would indicate success in graduate study.

Applicants who are admitted without a bachelor's degree in biomedical engineering may be required to complete collateral course work to make up deficiencies. Collateral course work will not count towards the fulfillment of degree requirements. International applicants are required to submit their scores on the Graduate Record Examination (GRE).



## COLLEGE OF ENGINEERING

### Requirements for the Doctor of Philosophy Degree in Biomedical Engineering

The doctoral degree program in biomedical engineering program of study is selected in consultation with a faculty advisor and the graduate program director. A minimum of 22 credits of course work beyond the bachelor's degree is required in addition to doctoral dissertation research. No more than 6 credits of 400-level courses may be counted towards the degree requirements.

Student's must complete the following:

- |  | CREDITS |
|--|---------|
| 1. All of the following core courses:  |         |
| BME 803 Research Methods   | 3       |
| BME 840 BioDesignI Q I   | 3       |
| BME 841 BioDesignI Q II  | 3       |
| BME 892 Biomedical Engineering Seminar   | 1       |
| 2. Complete at least 12 credits in thematic elective courses at the 800-level or above. Must include an engineering science course, a life science course, a mathematics/statistics/computational course, and another elective course chosen from a list of approved courses maintained by the department. |         |
| 3. Successful completion of the written and oral portions of the comprehensive examination by the end of the 4th semester in the program.  |         |
| 4. Complete 24 credits of BME 999 Doctoral Dissertation Research.  |         |
| 5. Successful completion of a dissertation and final oral examination in defense of the dissertation.  |         |

## DEPARTMENT of BIOSYSTEMS and AGRICULTURAL ENGINEERING

**Bradley P. Marks, Chairperson**

The mission of the Department of Biosystems and Agricultural Engineering is to improve quality of life by integrating and applying principles of engineering and biology to systems involving food, environment, energy, and health. The Department of Biosystems and Agricultural Engineering is administered jointly by the College of Agriculture and Natural Resources and the College of Engineering.

### UNDERGRADUATE PROGRAM

The department offers a Bachelor of Science degree program with a major in biosystems engineering through the College of Engineering. A Minor in Smart Agricultural Systems is also available. That program is described below.

The department also offers a Minor in Technology Systems Management through the College of Agriculture and Natural Resources. For information about that program, refer to the statement on the *Department of Biosystems and Agricultural Engineering* in the *College of Agriculture and Natural Resources* section of this catalog.

Students who are enrolled in the Bachelor of Science degree program with a major in biosystems engineering may elect a Minor in Plant, Animal and Microbial Biotechnology. For additional information, refer to the *Minor in Plant, Animal and Microbial Biotechnology* statement in the *College of Agriculture and Natural Resources* section of this catalog.

### BIOSYSTEMS ENGINEERING

#### Bachelor of Science

Biosystems engineers design solutions to technical problems that involve a critical biological component. They apply quantitative skills to create products, processes, and systems that improve human existence. Working at the interface of engineering and biology, biosystems engineers are engaged in the most important challenges of our time.

Biosystems engineers may, for example, design pathogen control processes to protect the safety of our food supply, constructed wetlands to improve water quality and quantity, biomass conversion processes to sustainably supply renewable energy and products, and/or diagnostic and risk modeling systems to protect and enhance human and animal health. Biosystems engineers are sought after by a wide variety of employers that need creative individuals to integrate principles of engineering and biology, including food manufacturers, environmental consulting firms, health industries, and government agencies.

The Bachelor of Science Degree program in Biosystems Engineering is accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org).

#### Requirements for the Bachelor of Science Degree in Biosystems Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Biosystems Engineering.

The University's Tier II writing requirement for the Biosystems Engineering major is met by completing Biosystems Engineering 334 or 485. Those courses are referenced in item 3. a below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

	CREDITS
a. All of the following courses:	
BE 101 Introduction to Biosystems Engineering	1
BE 201 Drafting in Biosystems Engineering	1
BE 230 Engineering Analysis of Biological Systems	3
BE 332 Engineering Properties of Biological Materials	3
BE 334 Biosystems Engineering Laboratory Practice (W)	3
BE 350 Heat and Mass Transfer in Biosystems	3
BE 351 Thermodynamics for Biological Engineering	3
BE 360 Microbial Systems Engineering	3
BE 385 Engineering Design and Optimization for Biological Systems	3
BE 485 Biosystems Design Techniques (W)	3
BE 487 Biosystems Design Project	3
BS 161 Cell and Molecular Biology	3
BS 162 Organismal and Population Biology	3
CE 221 Statics	3
CE 321 Introduction to Fluid Mechanics	4
CEM 143 Survey of Organic Chemistry	4
CEM 151 General and Descriptive Chemistry	4
CEM 161 Chemistry Laboratory I	1
b. One of the following courses (2 credits):	
BS 171 Cell and Molecular Biology Laboratory	2
BS 172 Organismal and Population Biology Laboratory	2
c. One of the following courses (3 or 4 credits):	

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IBIO 341	Fundamental Genetics	4
IBIO 355	Ecology	3
MMG301	Introductory Microbiology	3
PLB 301	Introductory Plant Physiology	3
PSL 250	Introductory Physiology	4
d. One of the following courses (3 or 4 credits):		
CSS 442	Agricultural Ecology	3
CSS 451	Biotechnology Applications for Plant Breeding and Genetics	3
FOR 406	Applied Forest Ecology: Silviculture	3
FSC 440	Food Microbiology	3
MMG365	Medical Microbiology	3
MMG404	Human Genetics	3
MMG425	Microbial Ecology	3
MMG445	Microbial Biotechnology (W)	3
PLB 402	Biology of Fungi	4
PSL 425	Physiological Biophysics	3
e. Four of the following courses (12 credits):		
BE 444	Biosensors for Medical Diagnostics	3
BE 449	Human Health Risk Analysis for Engineering Controls	3
BE 456	Electric Power and Control	3
BE 469	Sustainable Bioenergy Systems	3
BE 477	Food Engineering: Fluids	3
BE 478	Food Engineering: Solids	3
BE 481	Water Resources Systems Analysis and Modeling	3
BE 482	Engineering Ecological Treatment Systems	3
BE 484	Water Resource Recovery Engineering	3
CHE 468	Biomass Conversion Engineering	3

### Concentrations in Biosystems Engineering

The department offers concentrations for students who wish to focus on a specific application area in the discipline. The concentrations are available to, but not required of, any student enrolled in the Bachelor of Science degree program in Biosystems Engineering. Courses completed to satisfy requirement 3. above may also be used to satisfy the requirements of a concentration. The concentration will be noted on the students transcript.

#### Bioenergy and Bioproduct Engineering

To earn a Bachelor of Science degree in Biosystems Engineering with a bioenergy and bioproduct engineering concentration, students must complete degree requirements 1., 2., and 3. above and the following:

		CREDITS
1. All of the following courses (9 credits):		
BE 469	Sustainable Bioenergy Systems	3
CHE 468	Biomass Conversion Engineering	3
CSS 467	Bioenergy Feedstock Production	3
2. Two of the following courses (6 to 8 credits):		
CHE 481	Biochemical Engineering	3
CSS 442	Agricultural Ecology	3
CSS 451	Biotechnology Applications for Plant Breeding and Genetics	3
FOR 406	Applied Forest Ecology: Silviculture	3
FOR 427	Biomass and Bioproducts Chemistry	3
FOR 465	Natural Resource Policy	3
FW 444	Conservation Biology	3
GLG 435	Geomicrobiology	4
MC 450	International Environmental Law and Policy	3
ME 417	Design of Alternative Energy Systems	3
ME 422	Introduction to Combustion	3
MMG425	Microbial Ecology	3
MMG445	Microbial Biotechnology (W)	3
PLB 402	Biology of Fungi	4

#### Biomedical Engineering

To earn a Bachelor of Science degree in Biosystems Engineering with a biomedical engineering concentration, students must complete degree requirements 1., 2., and 3. above and the following:

		CREDITS
1. Both of the following courses (6 credits):		
BE 444	Biosensors for Medical Diagnostics	3

BE 449	Human Health Risk Analysis for Engineering Controls	3
2. One of the following courses (3 credits):		
MMG365	Medical Microbiology	3
MMG404	Human Genetics	3
PSL 425	Physiological Biophysics	3
3. Two of the following courses (5 or 6 credits):		
BE 440	Entrepreneurial Engineering for Innovation in Health and Safety	3
BLD 204	Mechanisms of Disease	3
BLD 313	Quality in Clinical Laboratory Practice	3
BLD 430	Molecular Diagnostics	2
BLD 434	Clinical Immunology	3
ECE 445	Biomedical Instrumentation	3
ME 494	Biofluid Mechanics and Heat Transfer	3
MMG365	Medical Microbiology	3
MMG404	Human Genetics	3
MSE 425	Biomaterials and Biocompatibility	3
PLB 400	Introduction to Bioinformatics	3
PSL 425	Physiological Biophysics	3
Courses used to fulfill requirement 2. in this concentration may not be used to fulfill this requirement.		

#### Ecosystems Engineering

To earn a Bachelor of Science degree in Biosystems Engineering with a ecosystems engineering concentration, students must complete degree requirements 1., 2., and 3. above and the following:

		CREDITS
1. All of the following courses (9 credits):		
BE 481	Water Resources Systems Analysis and Modeling	3
BE 482	Engineering Ecological Treatment Systems	3
BE 484	Water Resource Recovery Engineering	3
2. One of the following courses (3 credits):		
CSS 442	Agricultural Ecology	3
MMG425	Microbial Ecology	3
3. Two of the following courses (5 or 6 credits):		
CSS 210	Fundamentals of Soil Science	3
CSS 330	Soil Chemistry	2
CSS 360	Soil Biology	3
CSS 442	Agricultural Ecology	3
CSS 455	Environmental Pollutants in Soil and Water	3
ENE 422	Applied Hydraulics	3
FOR 340	Forest Ecology	3
FW 417	Wetland Ecology and Management	3
FW 420	Stream Ecology	3
FW 444	Conservation Biology	3
GEO 402	Agricultural Climatology	3
MC 450	International Environmental Law and Policy	3
MMG425	Microbial Ecology	3
PLB 418	Plant Systematics	3
PLB 443	Restoration Ecology	3
Courses used to fulfill requirement 2. in this concentration may not be used to fulfill this requirement.		

#### Food Engineering

To earn a Bachelor of Science degree in Biosystems Engineering with a food engineering concentration, students must complete degree requirements 1., 2., and 3. above and the following:

		CREDITS
1. All of the following courses (9 credits):		
BE 477	Food Engineering: Fluids	3
BE 478	Food Engineering: Solids	3
FSC 440	Food Microbiology	3
2. Two of the following courses, one of which must be at the 400-level (6 or 7 credits):		
BMB 200	Introduction to Biochemistry	4
FSC 211	Principles of Food Science	3
FSC 401	Food Chemistry	3
FSC 430	Food Processing: Fruits and Vegetables	3
FSC 431	Food Processing: Cereals	3
FSC 432	Food Processing: Dairy Foods	3
FSC 433	Food Processing: Muscle Foods	3

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### MINOR IN SMART AGRICULTURAL SYSTEMS

The Minor in Smart Agricultural Systems, which is administered by the Department of Biosystems and Agricultural Engineering, is available for students with majors in Applied Engineering Sciences, Biosystems Engineering, Computational Data Science, Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, Technology Engineering, and Lyman Briggs Computer Science who are interested in smart technology for management decision support and who plan to pursue careers in agriculture or natural resources. The minor will provide an opportunity for students to gain a working knowledge of digital technologies necessary to monitor and manage aspects of agriculture, food, natural resources, and bioenergy systems.

With the approval of the department and college that administer the student's degree program, the courses that are used to satisfy the minor may also be used to satisfy the requirements for the bachelor's degree. At least 10 unique credits counted towards the requirements for a student's minor must not be used to fulfill the requirements for that student's major.

Students who plan to complete the requirements of the minor should consult the Smart Agricultural Systems minor program coordinator in the Department of Biosystems Engineering and have their program of study approved in advance and in writing.

### Requirements for the Minor in Smart Agricultural Systems

Students must complete a minimum of 16 credits from the following:

	CREDITS
1. All of the following courses (10 credits):	
BE 221 Introduction to Smart Agriculture	1
BE 321 Principles of Precision Agriculture	3
BE 421 Sensors and Robotics for Agricultural Systems	3
BE 422 Crop Modeling and Optimization	3
2. Two of the following courses (6 to 8 credits):	
BE 449 Human Health Risk Analysis for Engineering Controls	3
BE 456 Electric Power and Control	3
BE 481 Water Resources Systems Analysis and Modeling	3
BE 482 Engineering Ecological Treatment Systems	3
CSE 404 Introduction to Machine Learning	3
CSE 440 Introduction to Artificial Intelligence	3
CSE 480 Database Systems	3
CSE 482 Big Data Analysis	3
CSS 467 Bioenergy Feedstock Production	3
ECE 416 Digital Control	4
ECE 417 Robotics	4
ECE 431 Smart Sensor Systems	3
ECE 434 Autonomous Vehicles	3
ECE 477 Microelectronic Fabrication	3
FOR 419 Applications of GIS to Natural Resources Management	4
ME 417 Design of Alternative Energy Systems	3
ME 451 Control Systems	4
ME 456 Mechatronic System Design	3
TNG 335 Computer Security Fundamentals	3
TNG 355 Networks and Network Security	3
TNG 440 Robotics, Automation, and Controls	3

### GRADUATE STUDY

The department offers Master of Science and Doctor of Philosophy programs in biosystems engineering through the College of Agriculture and Natural Resources. For information about those programs, refer to the statement on the

Department of Biosystems and Agricultural Engineering in the College of Agriculture and Natural Resources section of this catalog.

## DEPARTMENT of CHEMICAL ENGINEERING and MATERIALS SCIENCE

**Christina Chan, Chairperson**

The undergraduate and graduate programs of the Department of Chemical Engineering and Materials Science have been training top-quality graduates for over 75 years. Graduates from the Department of Chemical Engineering and Materials Science are highly sought after to create solutions for important technological and societal problems. The faculty is dedicated to strong classroom instruction and world-class research focused in the areas of energy and sustainability, advanced materials and nanotechnology, and biotechnology and bioengineering.

### UNDERGRADUATE PROGRAMS

The Department of Chemical Engineering and Materials Science offers two Bachelor of Science degree programs, one in chemical engineering and one in materials science and engineering. Students learn to convert low-value raw materials into high-value products. Students learn how to analyze and understand different processes and how, at the macroscopic, microstructural, and atomistic/molecular levels, these processes result in different properties in the final product. Emphasis is placed on developing students who understand the technical aspects of production, the environmental, economic, and societal impact of engineering, and who possess a desire for lifelong learning and growth. Optional concentrations are available for students to focus their programs of study on areas of particular interest.

Graduates are trained to succeed in multidisciplinary teams that interface between disciplines. They work across a broad spectrum of fields including industrial chemicals, automotive, metals, plastics, petroleum processing, pharmaceuticals, textiles, food, electronics, energy related materials, sensors, and biomedical technology. Within these fields, our graduates are involved in research and development of products and processes, in the design and operation of manufacturing facilities, and in management and product quality control.

### CHEMICAL ENGINEERING

Chemical engineers convert raw materials to finished products via pathways involving chemical and physical changes. The principles of mass, energy, and momentum conservation, chemical reactions, thermodynamics, and economics are applied to develop new products and to design and operate manufacturing facilities to produce products that benefit society. Chemical engineering principles are, in turn, based on

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the sciences of chemistry, biology, mathematics, and physics, which form the underlying foundation of the discipline.

Students in this degree program will study the application of chemical engineering principles to biochemical and biomedical systems, nanoscale devices, polymer processing, and novel energy systems. Principles of sustainability, environmentally-friendly “green” processing, entrepreneurship, and other emerging topics are also addressed in courses and concentrations.

The Bachelor of Science Degree program in Chemical Engineering is accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org) under the General Criteria and the Program Criteria for Chemical, Biochemical, Biomolecular and Similarly Named Engineering Programs.

### Requirements for the Bachelor of Science Degree in Chemical Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Chemical Engineering.

The University's Tier II writing requirement for the Chemical Engineering major is met by completing Chemical Engineering 316 and 433. Those courses are referenced in item 3. a. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. The alternative track requirement for Integrative Studies in Biological Sciences in Chemical Engineering is Biological Science 161. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

	CREDITS
a. All of the following courses (54 credits):	
BS 161 Cell and Molecular Biology	3
CEM 152 Principles of Chemistry	3
CEM 161 Chemistry Laboratory I	1
CEM 162 Chemistry Laboratory II	1
CEM 351 Organic Chemistry I	3
CEM 352 Organic Chemistry II	3
CEM 355 Organic Laboratory I	2
CHE 201 Material and Energy Balances	3
CHE 210 Modeling and Analysis of Transport Phenomena	3
CHE 301 Chemical Engineering as a Profession	1
CHE 311 Fluid Flow and Heat Transfer	3
CHE 312 Mass Transfer and Separations	4
CHE 316 Laboratory Practice and Statistical Analysis	4
CHE 321 Thermodynamics for Chemical Engineering	4
CHE 431 Chemical Reaction Engineering	4
CHE 432 Process Analysis and Control	3
CHE 433 Process Design and Optimization I	4
CHE 434 Process Design and Optimization II	2
CHE 473 Chemical Engineering Principles in Polymers and Material Systems	3

Note: Students must have a minimum grade-point of 2.0 in CHE 201.

- b. One of the following (4 or 6 credits):
  - (1) BMB 401 Comprehensive Biochemistry 4
  - (2) BMB 461 Advanced Biochemistry I 3
  - BMB 462 Advanced Biochemistry II 3

Note: If BMB 462 is taken to fulfill requirements 3. b., it will also count as a technical elective in item 3. e.
- c. One of the following courses (3 credits):

CHE 472 Polymeric Composite Materials Processing	3
CHE 481 Biochemical Engineering	3
- d. One of the following courses (3 credits):

CEM 483 Quantum Chemistry	3
CEM 484 Molecular Thermodynamics	3
- e. **Technical Electives.**

Students must complete at least 6 credits in courses selected from a list of approved technical electives available from the Department of Chemical Engineering and Materials Science.

### Concentrations in Chemical Engineering

In response to increasing interest in the application of chemical engineering principles to related fields, the Department of Chemical Engineering and Materials Science offers concentrations in biochemical engineering, bioenergy, biomedical engineering, environmental engineering, food science, and polymer science and engineering to students wishing an area of concentration in the degree. Concentrations are available to, but not required of, any student enrolled in the Bachelor of Science degree program in chemical engineering. The concentration will be noted on the student's transcript.

NOTE: Completing the Bachelor of Science degree in chemical engineering with a concentration may require more than 128 credits. For any concentration, up to 3 credits of Independent Study (CHE 490) related to the subject area may be applied with approval of the Department of Chemical Engineering and Materials Science.

#### Biochemical Engineering

To earn a Bachelor of Science degree in Chemical Engineering with a biochemical engineering concentration, students must complete requirements 1., 2., 3. a., and 3.d. above and the following:

Both of the following courses (6 credits):

CHE 481 Biochemical Engineering	3
MGI 301 Introductory Microbiology	3

One of the following tracks (11 to 13 credits):

*Track 1* (12 or 13 credits):

The following course (4 credits):

BMB 401 Comprehensive Biochemistry	4
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Three of the following courses (8 or 9 credits):

BMB 805 Protein Structure, Design, and Mechanism	3
BMB 829 Special Problems in Macromolecular Analysis and Synthesis	2
CHE 882 Advanced Biochemical Engineering	3
CHE 883 Multidisciplinary Bioprocessing Laboratory	3
MGI 409 Eukaryotic Cell Biology	3
MGI 421 Prokaryotic Cell Physiology	3
MGI 431 Microbial Genetics	3

*Track 2* (11 or 12 credits):

Both of the following courses (6 credits):

BMB 461 Advanced Biochemistry I	3
BMB 462 Advanced Biochemistry II	3

Two of the following courses (5 or 6 credits):

BMB 805 Protein Structure, Design, and Mechanism	3
BMB 829 Special Problems in Macromolecular Analysis and Synthesis	2
CHE 882 Advanced Biochemical Engineering	3
CHE 883 Multidisciplinary Bioprocessing Laboratory	3
MGI 409 Eukaryotic Cell Biology	3
MGI 421 Prokaryotic Cell Physiology	3
MGI 431 Microbial Genetics	3

#### Bioenergy and Bioproducts

To earn a Bachelor of Science degree in Chemical Engineering with a bioenergy and bioproducts concentration, students must complete requirements 1., 2., 3.a., 3.b., and 3.d. above and the following:

All of the following courses (9 credits):

CHE 468 Biomass Conversion Engineering	3
CHE 481 Biochemical Engineering	3
CSS 467 Bioenergy Feedstock Production	3

One of the following courses (3 credits):

BE 469 Sustainable Bioenergy Systems	3
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BE 869 Life Cycle Assessment for Bioenergy and Bioproduct Systems	3
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One of the following courses (3 credits):

AFRE829 Economics of Environmental Resources	3
CHE 882 Advanced Biochemical Engineering	3

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CHE 883	Multidisciplinary Bioprocessing Laboratory	3
FOR 466	Natural Resource Policy	3
MC 450	International Environmental Law and Policy	3

### Biomedical Engineering

To earn a Bachelor of Science degree in Chemical Engineering with a biomedical engineering concentration, students must complete requirements 1., 2., 3.a., 3.b., and 3.d. above and the following:

All of the following courses (10 credits):

CHE 481	Biochemical Engineering	3
MGI 409	Eukaryotic Cell Biology	3
PSL 431	Human Physiology I	4

One of the following courses (3 credits):

BME 860	NanoEngineering in Biomedicine	3
CHE 883	Multidisciplinary Bioprocessing Laboratory	3
ME 494	Biofluid Mechanics and Heat Transfer	3
MSE 425	Biomaterials and Biocompatibility	3

One of the following courses not taken above (3 or 4 credits):

ANTR350	Human Gross Anatomy for Pre-Health Professionals	4
BME 860	NanoEngineering in Biomedicine	3
CHE 883	Multidisciplinary Bioprocessing Laboratory	3
IBIO 341	Fundamental Genetics	4
ME 494	Biofluid Mechanics and Heat Transfer	3
MSE 425	Biomaterials and Biocompatibility	3

### Environmental

To earn a Bachelor of Science degree in Chemical Engineering with an environmental concentration, the student must complete requirements 1., 2., and 3. a., 3.b., and 3.d. above and the following:

Both of the following courses (6 credits):

CHE 481	Biochemical Engineering	3
ENE 380	Principles of Environmental Engineering and Science	3

Three of the following courses (9 credits):

CSS 865	Environmental Organic Chemistry	3
ENE 381	Environmental Chemistry	3
ENE 483	Water and Wastewater Engineering	3
ENE 489	Air Pollution: Science and Engineering	3

GBL 480 Environmental Law and Sustainability for Business:

	From Local to Global	3
GLG 421	Environmental Geochemistry	4
IBIO 446	Environmental Issues and Public Policy	3

### Food Science

To earn a Bachelor of Science degree in Chemical Engineering with a food science concentration, students must complete requirements 1., 2., 3. a., 3. b., 3.c., and 3.d. above and all of the following:

All of the following courses (9 credits):

FSC 401	Food Chemistry	3
FSC 440	Food Microbiology	3
MGI 301	Introductory Microbiology	3

One of the following courses (3 credits):

BE 477	Food Engineering: Fluids	3
BE 478	Food Engineering: Solids	3
CEM 482	Science and Technology of Wine Production	3
CHE 483	Brewing and Distilled Beverage Technology	3
FSC 325	Food Processing: Unit Operations	3
FSC 455	Food and Nutrition Laboratory	3
FSC 470	Integrated Approaches to Food Product Development	3
FSC 481	Fermented Beverages	3

### Polymer Science and Engineering

To earn a Bachelor of Science degree in Chemical Engineering with a polymer science and engineering concentration, students must complete requirements 1., 2., 3. a., 3. b., and 3.d. above and all of the following:

All of the following courses (9 credits):

CE 221	Statics	3
CHE 472	Polymeric Composite Materials Processing	3
ME 222	Mechanics of Deformable Solids	3

Two of the following courses (6 or 7 credits):

CHE 871	Material Surfaces and Interfaces	3
CHE 872	Polymers and Composites: Manufacturing, Structure and Performance	3
MSE 370	Synthesis and Processing of Materials	3
MSE 426	Introduction to Composite Materials	3
PKG 323	Packaging with Plastics	4

## MATERIALS SCIENCE and ENGINEERING

Materials Science and Engineering majors learn to select and create materials used to realize engineering designs in fields such as bioengineering, microelectronics and aerospace. They also learn how to manipulate the elements of matter into the atomic arrangements that ensure efficient and cost-effective materials performance, demanded by today's advanced applications.

Through the core course work, students gain the scientific and engineering foundation needed to design metallic, ceramic, polymeric, and composite materials and, in turn, components manufactured from these materials. Students may enhance the knowledge they gain in metals, ceramics, and polymers by completing a concentration in biomedical materials, manufacturing, polymers, or metallurgy. Students may also choose to enroll in electives of complementary fields such as business, electronic materials, or statistics. Honors students are encouraged to request an honors option with the instructors of MSE courses listed in item 3. a. below.

The Bachelor of Science Degree program in Materials Science and Engineering is accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org) under the General Criteria and the Program Criteria for Materials, Metallurgical, Ceramics and Similarly Named Engineering Programs.

### Requirements for the Bachelor of Science Degree in Materials Science and Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Materials Science and Engineering.

The University's Tier II writing requirement for the Materials Science and Engineering major is met by completing Materials Science and Engineering 466. That course is referenced in item 3. a. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading Graduation Requirements for All Majors in the College statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

	CREDITS
a. All of the following courses (41 credits):	
CE 221 Statics	3
CEM 152 Principles of Chemistry	3
CEM 161 Chemistry Laboratory I	1
ECE 345 Electronic Instrumentation and Systems	3
ME 222 Mechanics of Deformable Solids	3
MSE 250 Materials Science and Engineering	3
MSE 260 Electronic, Magnetic, Thermal and Optical Properties of Materials	3
MSE 310 Phase Equilibria in Materials	3
MSE 320 Mechanical Properties of Materials	3
MSE 331 Materials Characterization Methods I	2
MSE 360 Fundamentals of Microstructural Design	3
MSE 370 Synthesis and Processing of Materials	3
MSE 381 Materials Characterization Methods II	2
MSE 466 Design and Failure Analysis (W)	3
STT 351 Probability and Statistics for Engineering	3
Electrical and Computer Engineering 302 and 303 may be substituted for Electrical and Computer Engineering 345.	
b. Four of the following courses (12 credits):	
ME 477 Manufacturing Processes	3
MSE 425 Biomaterials and Biocompatibility	3

## COLLEGE OF ENGINEERING

MSE 474	Ceramic and Refractory Materials	3
MSE 460	Electronic Structure and Bonding in Materials and Devices	3
MSE 465	Design and Application of Engineering Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3
c. Complete at least 6 credits from 400-level courses within the College of Engineering.		
d. Complete at least 3 credits in courses selected from a list of approved technical electives available from the Department of Chemical Engineering and Materials Science.		

### Concentrations in Materials Science and Engineering

Students may elect to complete a more focused set of courses to enhance their ability to function at the interface with another scientific, engineering, or business discipline. Concentrations are available to, but not required of, any student enrolled in the Bachelor of Science degree in Materials Science and Engineering. Completing the Bachelor of Science degree in Materials Science and Engineering with a concentration may require more than 128 credits. The concentration will be noted on the student's transcript.

#### Biomedical Materials Engineering

To gain interdisciplinary skills in human biology and earn a Bachelor of Science degree in Materials Science and Engineering with a biomedical materials engineering concentration, students must complete requirement 3. a. above and the following (25 credits):

1. All of the following courses (12 credits):
 

ANTR350	Human Gross Anatomy for Pre-Health Professionals	3
CEM 251	Organic Chemistry I	3
Or		
CEM 351	Organic Chemistry I	3
ME 495	Tissue Mechanics	3
MSE 425	Biomaterials and Biocompatibility	3
2. One of the following courses (4 credits):
 

PSL 250	Introduction to Physiology	4
PSL 310	Physiology for Pre-Health Professionals	4
3. Two of the following courses (6 credits):
 

ME 477	Manufacturing Processes	3
MSE 474	Ceramics and Refractory Materials	3
MSE 460	Electronic Structure and Bonding in Materials and Devices	3
MSE 465	Design and Application of Engineering Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3
4. At least 3 credits from a list of approved technical electives 6

#### Manufacturing Engineering

To gain interdisciplinary skills with business and design engineers for manufacturing projects and earn a Bachelor of Science degree in Materials Science and Engineering with a manufacturing engineering concentration, students must complete requirement 3. a. above and the following (21 credits):

1. All of the following courses (12 credits):
 

ECE 415	Computer Aided Manufacturing	3
ME 477	Manufacturing Processes	3
ME 478	Product Development	3
MSE 465	Design and Application of Engineering Materials	3
2. Three of the following courses (9 credits):
 

GBL 323	Introduction to Business Law	3
MSE 426	Introduction to Composite Materials	3
MSE 474	Ceramic and Refractory Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3

Completion of this concentration fulfills requirement 2. of the admission requirements for the Master of Science degree in Manufacturing and Engineering Management offered by The Eli Broad College of Business.

#### Metallurgical Engineering

To enhance the student's ability to characterize, process, and design with metals in association with mechanical engineers and earn a Bachelor of Science degree in Materials Science and Engineering with a metallurgical engineering concentration, students must complete requirement 3. a. above and the following (21 credits):

1. All of the following courses (18 credits):
 

ME 423	Intermediate Mechanics of Deformable Solids	3
ME 475	Computer Aided Design of Structures	3
ME 477	Manufacturing Processes	3
MSE 481	Spectroscopic and Diffraction Analysis of Materials	3
MSE 465	Design and Application of Engineering Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3
2. One of the following courses (3 credits):
 

ME 425	Experimental Mechanics	3
MSE 426	Introduction to Composite Materials	3

#### Polymeric Engineering

To gain interdisciplinary skills to facilitate interactions with chemical engineers and earn a Bachelor of Science degree in Materials Science and Engineering with a polymeric engineering concentration, students must complete requirement 3. a. above and the following (22 credits):

1. All of the following courses (19 credits):
 

CE 321	Introduction to Fluid Mechanics	4
CEM 251	Organic Chemistry I	3
Or		
CEM 351	Organic Chemistry I	3
CEM 252	Organic Chemistry II	3
Or		
CEM 352	Organic Chemistry II	3
CHE 472	Composite Materials Processing	3
CHE 473	Chemical Engineering Principles in Polymers and Materials Systems	3
MSE 426	Introduction to Composite Materials	3
2. Complete at least 3 credits in courses selected from a list of approved technical electives available from the Department of Chemical Engineering and Materials Science.

### MINOR IN MATERIALS SCIENCE AND ENGINEERING

The Minor in Materials Science and Engineering, which is administered by the Department of Chemical Engineering and Materials Science, provides students with a basic foundation in materials science that is applicable to many disciplines. The minor also offers opportunities for students to work in industry, research, or government, as well as to prepare for graduate study in materials science.

The minor is available as an elective to students in a bachelor's degree program in the College of Engineering, other than the Bachelor of Science Degree in Materials Science and Engineering. With the approval of the college, the courses that are used to satisfy the minor may also be used to satisfy the requirements for the bachelor's degree.

Students who plan to complete the requirements for the minor must apply to the Department of Chemical Engineering and Materials Science. To be accepted into the minor, the student must be admitted into the College of Engineering. Enrollment for some MSE courses may be limited. Application forms are available at [www.chems.msu.edu](http://www.chems.msu.edu).

#### Requirements for the Minor in Materials Science and Engineering

	CREDITS
Complete 18 credits from the following:	
1. Both of the following courses (6 credits):	
MSE 250 Materials Science and Engineering	3
MSE 360 Fundamentals of Microstructural Design	3
2. One of the following courses (3 credits):	
MSE 260 Electronic, Magnetic, Thermal and Optical Properties of Materials	3
MSE 310 Phase Equilibria in Materials	3
MSE 320 Mechanical Properties of Materials	3
MSE 370 Synthesis and Processing of Materials	3
3. Three of the following courses (9 credits):	

## COLLEGE OF ENGINEERING

MSE 310	Phase Equilibria in Materials	3
MSE 320	Mechanical Properties of Materials	3
MSE 370	Synthesis and Processing of Materials	3
MSE 410	Materials Foundations for Energy Applications	3
MSE 425	Biomaterials and Biocompatibility	3
MSE 460	Electronic Structure and Bonding in Materials and Devices	3
MSE 465	Design and Application of Engineering Materials	3
MSE 466	Design and Failure Analysis (W)	3
MSE 474	Ceramic and Refractory Materials	3
MSE 476	Physical Metallurgy of Ferrous and Aluminum Alloys	3
MSE 477	Manufacturing Processes	3
MSE 481	Spectroscopic and Diffraction Analysis of Materials	3

A course used to fulfill requirement 2. above may not be used to fulfill this requirement.

## GRADUATE STUDY

The Department of Chemical Engineering and Materials Science offers Master of Science and Doctor of Philosophy degree programs in chemical engineering and in materials science and engineering. A Graduate Certificate in Foundations in Chemical Engineering is also available. A wide range of course offerings and research activities allows an individual program to be designed to fit the background, capabilities, and aims of the student. Studies in the department may be supplemented with courses offered by other departments in the College of Engineering and in other colleges.

The graduate programs in chemical engineering and materials science and engineering are designed to develop research expertise needed for the graduate to serve as a principal investigator in industrial, government, or academic research. Course work is designed to expand the student's knowledge of engineering principles and applications. Each student conducts an extensive research project that significantly advances fundamental understanding of a chemical engineering or materials science system. Results of the research are documented in a thesis, dissertation, or research paper(s) for publication in a peer-reviewed journal.

## CHEMICAL ENGINEERING

Emphasis in the graduate programs in chemical engineering is placed upon a fundamental approach to chemical engineering principles and the applications of chemistry and advanced mathematics. Selected topics in chemical engineering are developed from a fundamental viewpoint, with opportunity for study and research in such areas as process design; thermodynamics; chemical reaction engineering; mass, heat, and momentum transfer; separations; polymers and composite materials; nanomaterials; and biochemical and biomedical engineering. The department has three primary thematic areas: energy and sustainability, nanotechnology and materials, and biotechnology and medicine.

### Master of Science

In addition to meeting the requirements of the University and of the College of Engineering, students must meet the requirements specified below.

### Admission

An applicant for admission to the master's degree program in chemical engineering must hold a bachelor's degree in chemical engineering or a related field and must have a grade-point average that would indicate success in graduate study.

International applicants must submit their scores on the Graduate Record Examination General Test.

Students who are admitted to the program with a bachelor's degree in a field related to chemical engineering will be required to complete the following collateral courses, in addition to the courses that are required for the master's degree:

	CREDITS
CHE 432 Process Systems Control	3
CHE 433 Process Design and Optimization I	3
CHE 804 Thermodynamics and Kinetics in Chemical Engineering	3
CHE 805 Transport and Separation Processes	3
Equivalent undergraduate-level chemical engineering courses may be substituted for Chemical Engineering 804 and 805.	

### Requirements for the Master of Science Degree in Chemical Engineering

The students must complete a total of 30 credits for the degree under Plan A (with thesis) or Plan B (without thesis), and meet the requirements specified below. Students in Plan A must complete a minimum of 20 credits at the 800-level or above. Students in Plan B must complete a minimum of 18 credits at the 800-level or above. Courses at the 400-level are acceptable as long as the minimum credit requirement is met at the 800-level. Courses below the 400-level are not acceptable.

#### Requirements for Both Plan A and Plan B:

	CREDITS
1. <b>Core Courses.</b> All of the following courses (12 credits):	
CHE 801 Advanced Chemical Engineering Calculations	3
CHE 821 Advanced Chemical Engineering Thermodynamics	3
CHE 822 Advanced Transport Phenomena	3
CHE 831 Advanced Chemical Reaction Engineering	3
2. <b>Supporting Courses.</b> Six credits in courses outside the Department of Chemical Engineering and Materials Science approved by the student's academic advisor.	
3. Complete 2 credits in CHE 892 Seminar.	

#### Additional Requirements for Plan A

- Complete 6 credits of CHE 899 Master's Thesis Research
- Additional elective credits as approved by the student's academic advisor.

#### Additional Requirements for Plan B

- Complete 6 to 9 credits in a coordinated technical minor as approved by the student's academic advisor.
- Pass a final examination, oral or written, given by the student's academic advisor.

### Doctor of Philosophy

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

### Admission

An applicant for admission to the Ph.D. degree program in chemical engineering must hold a bachelor's or master's degree in chemical engineering or a related field and must have a grade-point average that would indicate success in graduate study.

## COLLEGE OF ENGINEERING

Applicants must submit their scores on the Graduate Record Examination General Test.

Students may be required to complete additional collateral course work to fulfill deficiencies in their academic background. A grade of 3.0 or higher is required in each course. In some cases, students may be granted provisional status in the program until collateral course work has been satisfactorily completed. Collateral course work does not count towards fulfillment of degree requirements.

### Requirements for the Doctor of Philosophy Degree in Chemical Engineering

The Doctor of Philosophy degree in Chemical Engineering is comprised of course work, research, selection of an advisor, a qualifying examination, formation of a guidance committee and doctoral degree program, comprehensive examination, and successful completion of a dissertation and final oral examination in defense of the dissertation.

Students must complete the requirements specified by their guidance committee and must include the requirements specified below:

- |  | CREDITS |
|--|---------|
| 1. All of the following courses (13 credits):  |         |
| CHE 801 Advanced Chemical Engineering Calculations   | 3       |
| CHE 802 Research Methods   | 1       |
| CHE 821 Advanced Chemical Engineering Thermodynamics   | 3       |
| CHE 822 Advanced Transport Phenomena   | 3       |
| CHE 831 Advanced Chemical Reaction Engineering   | 3       |
| 2. Complete 5 credits of CHE 992 Seminar.  |         |
| 3. Students entering the program with a master's degree must complete 12 additional credits in consultation with the guidance committee. Students may receive a waiver for some of the required courses. Students who have a bachelor's degree are required to complete a minimum of 16 additional credits chosen in consultation with the guidance committee. |         |
| 4. Pass a qualifying examination consisting of a written component and an oral component.  |         |
| 5. Pass a comprehensive examination in the form of a research proposal defense containing a written proposal and an oral defense.  |         |
| 6. Complete a minimum of 24 credits and no more than 36 credits of CHE 999 Doctoral Dissertation Research and successfully defend the dissertation.  |         |
| 7. Present the results of the research in a public seminar during the final oral examination.  |         |

## MATERIALS SCIENCE AND ENGINEERING

### Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### Admission

The department welcomes applications from students who possess a bachelor's degree in a related engineering or science discipline. Students entering the program with a bachelor degree in a field other than Materials Science and Engineering may be required to complete additional collateral courses to fulfill deficiencies in their academic background. Collateral course work does not count towards the requirements for the degree program.

### Requirements for the Master of Science Degree in Materials Science and Engineering

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis) and meet the requirements specified below.

#### Requirements for Both Plan A and Plan B:

- |   |   |
|---|---|
| 1. Core Courses. All of the following courses (12 credits):         |   |
| MSE 851 Thermodynamics of Solids                                    | 3 |
| MSE 855 Advanced Rate Theory and Diffusion                          | 3 |
| MSE 860 Advanced Theory of Solids                                   | 3 |
| MSE 870 Electron Microscopy in Materials Science                    | 3 |
| Or  |   |
| MSE 881 Advanced Spectroscopy and Diffraction Analysis of Materials | 3 |

#### Additional Requirements for Plan A

- |   |   |
|---|---|
| 1. Complete the following course:   |   |
| CHE 892 Seminar   | 2 |
| 2. Complete 6 credits of MSE 899 Master's Thesis Research.  |   |
| 3. One course at the 400-level or above in mathematics or statistics as approved by the student's academic advisor. |   |
| 4. Submit a written thesis and oral presentation, administered by the student's advisory committee.                 |   |
| 5. A minimum of 16 credits must be at the 800-level or above as approved by the student's academic advisor.         |   |

#### Additional Requirements for Plan B

- |  |   |
|--|---|
| 1. Complete the following course:  |   |
| CHE 892 Seminar  | 2 |
| 2. One course at the 400-level or above in mathematics or statistics as approved by the student's academic advisor.  |   |
| 3. At least 6 to 9 credits completed in a coordinated technical minor as approved by the student's academic advisor. |   |
| 4. Additional elective credits as approved by the student's academic advisor.  |   |
| 5. A minimum of 18 credits at the 800-level or above as approved by the student's academic advisor.                  |   |
| 6. Pass a final examination or evaluation.   |   |

### Doctor of Philosophy

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### Admission

An applicant for admission to the Ph.D. degree program in materials science and engineering must hold a bachelor's or master's degree in materials science and engineering or a related field and must have a grade-point average that would indicate success in graduate study. Applicants must submit their scores on the Graduate Record Examination General Test.

Students entering the program with a bachelor's degree in a field other than Materials Science and Engineering may be required to complete additional collateral courses to fulfill deficiencies in their academic background. Collateral course work will not count towards degree requirements.



## COLLEGE OF ENGINEERING

### Requirements for the Doctor of Philosophy Degree in Materials Science and Engineering

Students must meet the requirements specified by their guidance committee and must meet the requirements specified below. Students entering the program with a bachelor's degree are required to complete a minimum of 13 additional credits selected in conjunction with the advisor and committee. Students entering the program with a master's degree are required to complete a minimum of 12 additional credits, but may receive a waiver for some of the required courses with approval of the advisor and committee.

	CREDITS
1. All of the following courses (13 credits):	
CHE 802 Research Methods	1
MSE 851 Thermodynamics of Solids	3
MSE 855 Advanced Rate Theory and Diffusion	3
MSE 860 Advanced Theory of Solids	3
MSE 870 Electron Microscopy in Materials Science	3
Or	
MSE 881 Advanced Spectroscopy and Diffraction Analysis of Materials	3
2. Complete 5 credits of CHE 992 Seminar.	
3. Complete one mathematics or statistics course at the 400-level or above.	3
4. Pass a qualifying examination consisting of a written component and an oral component.	
5. Pass a comprehensive examination in the form of a research proposal defense containing a written proposal and an oral defense.	
6. Complete a minimum of 24 credits of MSE 999 Doctoral Dissertation Research, with no more than 36 credits.	
7. Successfully defend the dissertation and present the results of the research in a public seminar during the final oral examination.	

### GRADUATE CERTIFICATE IN FOUNDATIONS IN CHEMICAL ENGINEERING

The Graduate Certificate in Foundations in Chemical Engineering provides a broad base of the key concepts relevant to chemical and biochemical process industries, including thermodynamics; reactor design; fluid flow; heat transfer; separations; and process control, economics, and design. The certificate is appropriate for graduates from other programs who seek to pursue graduate work in chemical engineering and for practitioners trained in other fields who seek to understand and apply chemical-engineering principles. The certificate is available only online.

#### Admission

Students are generally expected, but not required, to have bachelor's-level or significant training in a math, science or engineering field. Prospective students are encouraged to contact the Director of Graduate Studies in the Department of Chemical Engineering and Materials Science to determine if their background is a good fit for the certificate.

### Requirements for the Graduate Certificate in Foundations in Chemical Engineering

Complete all of the following courses with a minimum grade of 3.0 in each course:

	CREDITS
CHE 804 Foundations of Chemical Engineering I	3
CHE 805 Foundations of Chemical Engineering II	3
CHE 806 Foundations of Chemical Engineering III	3

## DEPARTMENT of CIVIL and ENVIRONMENTAL ENGINEERING

*Peter Savolainen, Chairperson*

### UNDERGRADUATE PROGRAMS

The Department of Civil and Environmental Engineering offers Bachelor of Science degrees in Civil Engineering and Environmental Engineering. Each program is described below.

#### CIVIL ENGINEERING

The civil engineering major is designed to provide graduates with a broad understanding of the physical factors involved in the planning, design, and operation of public and private facilities. The bachelor's degree program in civil engineering is oriented to the application of engineering principles to several areas of specialization, including transportation, structures, geotechnical engineering, environmental engineering, water resources, and pavements and materials.

The Bachelor of Science Degree program in Civil Engineering is accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org).

### Requirements for the Bachelor of Science Degree in Civil Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Civil Engineering.

The University's Tier II writing requirement for the Civil Engineering major is met by completing Civil Engineering 321 and 341. Those courses are referenced in item 3. a. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

	CREDITS
a. All of the following courses (46 credits):	
CE 221 Statics	3
CE 271 Introduction to Civil and Environmental Engineering	3
CE 273 Civil and Environmental Engineering Measurements	2
CE 274 Graphics for Civil and Environmental Engineers	1
CE 275 GIS for Civil and Environmental Engineers	1
CE 305 Introduction to Structural Analysis	3
CE 312 Soil Mechanics	4
CE 321 Introduction to Fluid Mechanics	4
CE 337 Civil Engineering Materials	4
CE 341 Transportation Engineering	3
CE 361 Computational Methods in Civil Engineering	3
CE 371 Sustainable Civil and Environmental Engineering Systems	3
CE 372 Risk Analysis in Civil and Environmental Engineering	3

## COLLEGE OF ENGINEERING

CE 495	Senior Design in Civil and Environmental Engineering	4
CE 496	Review for the CE and ENE Fundamentals of Engineering Exams	1
CEM 161	Chemistry Laboratory I	1
ME 222	Mechanics of Deformable Solids	3
b. One of the following courses (3 or 4 credits):		
GLG 201	Introduction to Earth and Planetary Sciences	4
GLG 203	Geology of the Great Lakes Region	3
c. <b>Design-intensive Electives.</b> Complete 12 or 13 credits of electives from the list below in at least four different areas (environmental, geotechnical, pavements, structures, transportation, and water resources).		
<b>Environmental</b>		
ENE 483	Water and Wastewater Engineering	4
ENE 489	Air Pollution: Science and Engineering	3
<b>Geotechnical</b>		
CE 418	Geotechnical Engineering	3
CE 485	Landfill Design	3
<b>Pavements</b>		
CE 431	Design and Analysis for New and Rehabilitated Pavements	4
<b>Structures</b>		
CE 405	Design of Steel Structures	3
CE 406	Design of Concrete Structures	3
<b>Transportation</b>		
CE 444	Principles of Traffic Engineering	3
CE 449	Highway Design	3
<b>Water Resources</b>		
ENE 421	Engineering Hydrology	3
ENE 422	Applied Hydraulics	3
d. <b>Technical Electives.</b> Complete 6 additional credits in courses not used to fulfill areas above or from the following:		
CE 400	Structural Mechanics	3
CE 407	Materials Engineering: Properties, Selection and Processing	3
CE 432	Pavement Rehabilitation	3
CE 448	Transportation Planning	3
CE 471	Construction Engineering – Equipment, Methods and Planning	3
CE 473	Smart and Sustainable Building Design and Operations	3
ENE 380	Principles of Environmental Engineering and Science	3
ENE 381	Environmental Chemistry	3
ENE 472	Life Cycle Assessment of Energy Technologies	3
ENE 487	Microbiology for Environmental Science and Engineering	3

## ENVIRONMENTAL ENGINEERING

The environmental engineering major is designed to provide graduates with the engineering and scientific principles to analyze, design, and manage environmental systems, including water supplies, wastewater treatment facilities, air pollution control systems, surface and groundwater resources, and landfills. The program offers a thorough background in engineering fundamentals, along with a broad understanding of mathematical, physical, chemical, and biological concepts as they relate to environmental engineering.

The Bachelor of Science Degree program in Environmental Engineering is accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org).

### Requirements for the Bachelor of Science Degree in Environmental Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Environmental Engineering.

The University's Tier II writing requirement for the Environmental Engineering major is met by completing Civil Engineering 321. That course is referenced in item 3. a. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences

that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major.

	CREDITS
a. All of the following courses (57 credits):	
BS 161 Cell and Molecular Biology	3
BS 162 Organismal and Population Biology	3
CE 221 Statics	3
CE 271 Introduction to Civil and Environmental Engineering	3
CE 274 Graphics for Civil and Environmental Engineers	1
CE 275 GIS for Civil and Environmental Engineers	1
CE 321 Introduction to Fluid Mechanics	4
CE 372 Risk Analysis in Civil and Environmental Engineering	3
CE 495 Senior Design in Civil and Environmental Engineering	4
CE 496 Review for the CE and ENE Fundamentals of Engineering Exams	1
CEM 161 Chemistry Laboratory I	1
CHE 201 Material and Energy Balances	3
ENE 371 Sustainable Civil Environmental Engineering Systems	3
ENE 380 Principles of Environmental Engineering and Science	3
ENE 381 Environmental Chemistry	3
ENE 421 Engineering Hydrology	3
ENE 422 Applied Hydraulics	3
ENE 480 Environmental Measurements Laboratory	2
ENE 483 Water and Wastewater Engineering	4
ENE 487 Microbiology for Environmental Science and Engineering	3
ENE 489 Air Pollution: Science and Engineering	3
b. One of the following courses (3 credits):	
CEM 142 General and Inorganic Chemistry	3
CEM 152 Principles of Chemistry	3
c. One of the following courses (3 or 4 credits):	
CHE 321 Thermodynamics for Chemical Engineering	4
ME 201 Thermodynamics	3
d. One of the following courses (3 or 4 credits):	
GLG 201 Introduction to Earth and Planetary Sciences	4
GLG 203 Geology of The Great Lakes Region	3
e. <b>Technical Electives.</b> Complete at least two courses for a minimum of 6 credits of electives from the list below, list above (e), or by approval of the department. Students may substitute a 3-credit experiential education experience for one of the three courses. The experience is obtained in a minimum of three out-of-classroom experiences through engineering cooperative education. Students must contact the department for approval.	
ANS 427 Environmental Toxicology and Society	3
BE 449 Human, Health Risk Analysis for Engineering Controls	3
BE 469 Sustainable Bioenergy Systems	3
BE 482 Engineering Ecological Treatment Systems	3
BE 484 Water Resource Recovery Engineering	3
CE 473 Smart and Sustainable Building Design and Operations	3
CE 485 Landfill Design	3
CSS 455 Environmental Pollutants in Soil and Water	3
CSUS 320 Environmental Planning and Management	3
ENE 472 Life Cycle Assessment of Energy Technologies	3
FW 353 Marine Biology	3
FW 417 Wetland Ecology and Management	3
FW 420 Stream Ecology	3
FW 472 Limnology	3
GLG 303 Oceanography	4
GLG 411 Hydrogeology	3
GLG 412 Glacial Geology and the Record of Climate Change	4
GLG 421 Environmental Geochemistry	4
IBIO 355 Ecology	3
IBIO 446 Environmental Issues and Public Policy	3
ISS 310 People and Environment (I)	4
PLB 443 Restoration Ecology	3

## COLLEGE OF ENGINEERING

### GRADUATE STUDY

The Department of Civil and Environmental Engineering offers the graduate degree programs that are listed below:

#### **Master of Science**

Civil Engineering  
Environmental Engineering

#### **Doctor of Philosophy**

Civil Engineering  
Environmental Engineering

The civil engineering degrees offer tracks in structural, materials, pavement, and geotechnical engineering, and hydrology and water resources. The environmental engineering degrees offer specializations in environmental chemistry and physical-chemical processes, environmental microbiology and biotechnology, and environmental hydrology and water resources.

The Master of Science degrees provide opportunities for students who seek to enter professional practice as specialists or to continue study in a doctoral program. The Doctor of Philosophy degrees are research focused, designed to prepare students for careers in teaching, research or advanced specialized practice.

### CIVIL ENGINEERING

Students in the master's and doctoral degree programs in civil engineering may pursue advanced study in the areas of geotechnical and pavement engineering, structural engineering, mechanics and materials; water resources; and transportation engineering.

#### **Master of Science**

Courses are selected in consultation with the academic advisor based upon the student's background. The courses in the final program of study are subject to the approval of the guidance committee.

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### **Admission**

An applicant for admission to the master's degree program in civil engineering should have a bachelor's degree in civil engineering or a related field and should have a grade-point average that would indicate success in graduate study. Depending on their undergraduate programs and their specialties within civil engineering, students who are admitted to the master's degree program with bachelor's degrees in fields related to civil engineering may be required to complete collateral courses.

All applicants are encouraged to submit their scores from the Graduate Record Examination General Test.

### Requirements for the Master of Science Degree in Civil Engineering

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis).

A student under Plan A must complete at least 20 credits at the 800-level or above, including 4 credits of Civil Engineering 899, but not more than 6 credits. Up to 10 credits of 400-level course work may be counted toward the degree. The student's program must be approved by the guidance committee.

A student under Plan B must complete at least 18 credits at the 800-level or above, including the completion of a research or design project through enrollment of at least 1 credit, but no more than 4 credits in Civil Engineering 892. Up to 12 credits of 400-level course work may be counted toward the degree. The student's program must be approved by the guidance committee.

#### **Doctor of Philosophy**

#### **Admission**

An applicant for admission to the Ph.D. degree program in civil engineering should have a bachelor's or master's degree in civil engineering or a related field and should have a grade-point average that would indicate success in graduate study.

All applicants are encouraged to submit their scores from the Graduate Record Examination General Test.

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified by their guidance committees.

### Requirements for the Doctor of Philosophy Degree in Civil Engineering

These general criteria are the same for all students, the specific requirements for each student are developed in consultation with the advisor and the guidance committee.

1. Students with a Master of Science degree in Civil Engineering must complete 12 credits of course work at the 800-level or above in consultation with their advisor and guidance committee.
2. Students admitted directly to the Doctor of Philosophy degree in Civil Engineering must also complete the requirements for the Master of Science degree in Civil Engineering as part of the doctoral plan of study.
3. Students entering the program with a bachelor's or master's degree in a field other than civil engineering may be required to complete additional collateral course work to fulfil deficiencies in their academic background as specified by the guidance committee. This course work will not count towards the requirements for the doctoral degree program.
4. Complete the following course during the first year of study:  
CE 900 Research Strategies and Methods in Civil Engineering 1
5. Complete 24 to 36 credits of CE 999 Doctoral Dissertation Research.
6. Complete a qualifying examination comprised of a written examination and an oral examination.
7. Complete a comprehensive examination comprised of a written thesis proposal and oral presentation. This examination must be completed at least six months prior to the doctoral dissertation defense.
8. Complete and successfully defend the dissertation and present the results of the dissertation research in a public seminar.

## COLLEGE OF ENGINEERING

### ENVIRONMENTAL ENGINEERING

Students in the master's and doctoral degree programs in environmental engineering may pursue advanced study in the areas of environmental chemistry and physical-chemical processes, environmental microbiology and biotechnology, and environmental hydrology and water resources.

#### Master of Science

Courses are selected in consultation with the academic advisor based upon the student's background. The courses in the final program of study are subject to the approval of the guidance committee.

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### Admission

Applicants for admission are expected to have a level of competency equivalent to that achieved by earning an undergraduate degree in environmental engineering, or in civil engineering with an environmental engineering specialization. The undergraduate program should have included courses in mathematics through differential equations, chemistry, physics (mechanics), fluid mechanics, computer programming, and the design of water and wastewater treatment processes.

Depending on their undergraduate programs and their specialties within environmental engineering, students who are admitted to the master's degree program with bachelor's degrees in fields related to environmental engineering may be required to complete collateral courses.

All applicants are encouraged to provide their scores from the Graduate Record Examination General Test.

#### Requirements for the Master of Science Degree in Environmental Engineering

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis).

A student under Plan A must complete at least 20 credits at the 800-level or above, including 4 credits of Environmental Engineering 899. Up to 10 credits of 400-level course work may be counted toward the degree. The student's program must be approved by the guidance committee.

A student under Plan B must complete at least 18 credits at the 800-level or above, including the completion of a research or design project through enrollment of at least 1 credit, but no more than 4 credits in Environmental Engineering 892. Up to 12 credits of 400-level course work may be counted toward the degree. The student's program must be approved by the guidance committee.

### Doctor of Philosophy

#### Admission

An applicant for admission to the Ph.D. degree program in environmental engineering should have a bachelor's or master's degree in environmental engineering or a related field and should have a grade-point average that would indicate success in graduate study.

All applicants are encouraged to submit their scores from the Graduate Record Examination General Test.

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified by their guidance committees.

#### Requirements for the Doctor of Philosophy Degree in Environmental Engineering

These general criteria are the same for all students, the specific requirements for each student are developed in consultation with the advisor and the guidance committee.

1. Students with a Master of Science degree in Environmental Engineering must complete 15 credits of coursework at the 800-level or above in consultation with their advisor and guidance committee.
2. Students admitted directly to the Doctor of Philosophy degree in Environmental Engineering must also complete the requirements for the Master of Science degree in Environmental Engineering as part of the doctoral plan of study.
3. Students entering the program with a bachelor's or master's degree in a field other than environmental engineering may be required to complete additional collateral course work to fulfill deficiencies in their academic background as specified by the guidance committee.

This course work will not count towards the requirements for the doctoral degree program.

4. Complete the following course during the first year of study:  
ENE 900 Research Strategies and Methods in Environmental Engineering and Science 1
5. Complete 24 to 36 credits of ENE 999 Doctoral Dissertation Research.
6. Complete a qualifying examination comprised of a written examination and an oral examination.
7. Complete a comprehensive examination comprised of a written thesis proposal and oral presentation. This examination must be completed at least six months prior to the doctoral dissertation defense.
8. Complete and successfully defend the dissertation and present the results of the dissertation research in a public seminar.

### DATA-ENABLED WATER SUSTAINABILITY AND EQUITY

#### Graduate Certificate

The Graduate Certificate in Data-enabled Water Sustainability and Equity (DWSE) will equip students with fundamental knowledge of the three dimensions of the WaterCube and with skills to integrate these areas for understanding and addressing real-world water issues. The graduate certificate requires students to complete a series of four courses, totaling 10 credits. Students will have options for fulfilling course requirements providing flexibility to incorporate the requirements into their programs of study without extending their time to degree.

## Admission

For admission to the Graduate Certificate in Data-enabled Water Sustainability and Equity, students must complete an application form which includes:

1. a plan for completing the certificate requirements. Students will indicate which courses they will take to meet the program requirements, provide a brief justification for their choices, and provide a timeline for completion.
2. a statement of interest. Students will briefly describe their interest in Data-enabled Water Sustainability and Equity and their reason(s) for pursuing the graduate certificate.

## Requirements for the Graduate Certificate in Data-enabled Water Sustainability and Equity

Students must complete a minimum of 10 credits from the following:

	CREDITS
1. The following course (1 credit):	
FW 867 Water: A Global Perspective	1
2. One of the following data science courses (3 credits):	
CMSE 801 Introduction to Computational Modeling and Data Analysis	3
CSE 404 Introduction to Machine Learning	3
CSE 881 Data Mining	3
GEO 429 Programming with Spatial Data	3
GEO 866 Spatial Data Analysis	4
3. One of the following social science courses (3 credits):	
AIIS 801 Indigenous Theories and Methodologies	3
CSUS858 Gender, Justice and Environmental Change: Issues and Concepts	3
CSUS848 Community Based Natural Resource Management in International Development	3
SOC 865 Environmental Sociology	3
4. One of the following experiential learning courses (3 credits):	
ESP 804 Environmental Applications and Analysis	3
FW 868 Water Policy and Management	3

CMSE 801, GEO 429, and GEO 866 are recommended for students new to programming and modeling. Additional courses at the 400-level or above may be used to fulfill requirement 2. Or requirement 3, if approved by the program director. Students must have a minimum 3.0 grade-point average in courses applied to the certificate in order for it to be awarded.

# DEPARTMENT of COMPUTATIONAL MATHEMATICS, SCIENCE and ENGINEERING

## Edward Brown, Chairperson

Computational Mathematics, Science and Engineering is the multidisciplinary field concerned with using advanced computing to solve complex problems pertaining to computational modeling and data science. Areas of interest include the development and analysis of algorithms, high performance computing, including both parallel computing and heterogeneous architectures, and the application of both algorithms and high-performance computing to modeling and data analysis, exploration, and visualization. The department offers a wide range of courses in computational and data

science. Graduates will use their skills in large-scale computing and data science to address a wide variety of problems in science, engineering, and other fields.

The Department of Computational Mathematics, Science and Engineering is administered jointly by the colleges of Natural Science and Engineering.

## UNDERGRADUATE PROGRAMS

The department offers a minor in Computational Mathematics, Science and Engineering. The minor is a minimum of 17 credits and builds up on the first two undergraduate CMSE courses, CMSE 201 and 202. The purpose of the minor is to teach students foundational concepts in computational modeling and data science, and to have them apply these to domain-specific challenges. Mastery of these subject areas are attained through a variety of courses offered by CMSE, augmented by discipline-specific courses and project-based work through other departments on campus. For additional information on the minor, see the *Department of Computational Mathematics, Science and Engineering* section in the *College of Natural Science* section of this catalog.

## GRADUATE STUDY

The Department of Computational Mathematics, Science and Engineering offers the programs listed below:

### Master of Science

Computational Mathematics, Science and Engineering

### Doctor of Philosophy

Computational Mathematics, Science and Engineering

### Graduate Certificate

Computational Modeling

High-Performance Computing

Study for the department's graduate degree programs is administered by the College of Engineering.

### Master of Science

The Master of Science degree in Computational Mathematics, Science, and Engineering provides students broad and deep knowledge of the fundamental techniques used in computational modeling and data science, as well as significant exposure to at least one application domain.

## Admission

Admission to graduate study in computational mathematics, science, and engineering is primarily to the doctoral program. Under certain circumstances, the program may consider application for admission to the master's degree program for students who wish to earn the master's degree in preparation for the doctoral program in computational mathematics, science, and engineering, or another doctoral program, or in pursuit of other professional goals.

To be considered for admission to the master's degree, a student must:

1. have a four-year bachelor's degree in any area.

## COLLEGE OF ENGINEERING

2. have a strong interest in computational and/or data science.
3. have taken course work in calculus through differential equations, and have a working knowledge of linear algebra, basic statistics, and basic numerical methods.
4. be proficient in at least one programming language.

In addition to meeting the requirements of the university and of the College of Natural Science, students must meet the requirements specified below.

### Requirements for the Master of Science Degree in Computational Mathematics, Science, and Engineering

A total of 30 credits is required for the degree under either Plan A (with thesis) or Plan B (without thesis). The student's program of study must be approved by the student's guidance committee and must meet the requirements specified below.

#### CREDITS

#### Requirements for Both Plan A and Plan B

1. Complete three of the following courses (9 credits):

CMSE 820	Mathematical Foundations of Data Science	3
CMSE 821	Numerical Methods for Differential Equations	3
CMSE 822	Parallel Computing	3
CMSE 823	Numerical Linear Algebra, I	3

Additional details on applicable course work can be found in the CMSE graduate handbook at [www.cmse.msu.edu](http://www.cmse.msu.edu).
2. Complete additional course work in one or more cognate areas chosen in consultation with the student's guidance committee as specified in the CMSE graduate handbook at [www.cmse.msu.edu](http://www.cmse.msu.edu).
3. All students must complete Responsible Conduct of Research Training.

#### Additional Requirements for Plan A:

1. The following course:

CMSE 899	Master's Thesis Research	4 to 8
----------	--------------------------	--------
2. Successful completion and defense of a thesis based on original research on a problem in computational and/or data science. The thesis research will culminate in a written thesis to be submitted to, and accepted by, a guidance committee. An oral examination of the student's work may be required.

#### Additional Requirements for Plan B:

1. Completion of additional course work determined in consultation with the student's guidance committee.
2. Completion of a final examination or evaluation.

### Doctor of Philosophy

The Doctor of Philosophy degree in Computational Mathematics- Science, and Engineering provides students broad and deep knowledge of the fundamental techniques used in computational modeling and data science, significant exposure to at least one application domain, and the opportunity to conduct significant original research in algorithms and/or applications relating to computational and data science.

#### Admission

Admission to graduate study in computational mathematics, science, and engineering is primarily to the doctoral program.

To be considered for admission to the doctoral degree, a student must:

1. have a four-year bachelor's degree in any area.
2. have a strong interest in computational and/or data science.
3. have taken course work in calculus through differential equations, and have a working knowledge of linear algebra, basic statistics, and basic numerical methods.

4. be proficient in at least one programming language.

In addition to meeting the requirements of the university and of the College of Natural Science, students must meet the requirements specified below.

### Requirements for the Doctor of Philosophy Degree in Computational Mathematics, Science, and Engineering

The student's program of study must be approved by the student's guidance committee and must meet the requirements specified below.

#### CREDITS

1. Complete the following courses (12 credits):

CMSE 820	Mathematical Foundations of Data Science	3
CMSE 821	Numerical Methods for Differential Equations	3
CMSE 822	Parallel Computing	3
CMSE 823	Numerical Linear Algebra, I	3

Additional details on applicable course work can be found in the CMSE graduate handbook at [www.cmse.msu.edu](http://www.cmse.msu.edu).
2. Complete additional course work to total a minimum of 30 credits beyond the bachelor's degree in one or more cognate areas chosen in consultation with the student's guidance committee as specified in the CMSE graduate handbook at [www.cmse.msu.edu](http://www.cmse.msu.edu).
3. Complete at least 24 credits and no more than 36 credits of CMSE 999 Doctoral Dissertation Research.
4. Pass a written or practical qualifying examination.
5. Pass an oral or written comprehensive examination no less than six months before the defense of the student's dissertation.
6. Successfully defend the doctoral dissertation based on original research in algorithms pertaining to, or applications of computational and data science.
7. All students must complete Responsible Conduct of Research Training.

### GRADUATE CERTIFICATE IN COMPUTATIONAL MODELING

The Graduate Certificate in Computational Modeling is intended for students with interest in applying computational and data science approaches to their research problems, or who generally desire broad training in computational modeling and methodology.

### Requirements for the Graduate Certificate in Computational Modeling

#### CREDITS

Students must complete a minimum of 9 credits from the following:

1. Two of the following core courses (6 credits):

CMSE 801	Introduction to Computational Modeling	3
CMSE 802	Methods in Computational Modeling	3
CMSE 820	Mathematical Foundations of Data Science	3
CMSE 821	Numerical Methods for Differential Equations	3
CMSE 822	Parallel Computing	3
CMSE 823	Numerical Linear Algebra I	3
2. One or more additional courses selected from the following:

AST 911	Numerical Techniques in Astronomy	2
CEM 883	Computational Quantum Chemistry	3
CEM 888	Computational Chemistry	3
CMSE 801	Introduction to Computational Modeling	3
CMSE 802	Methods in Computational Modeling	3
CMSE 820	Mathematical Foundations of Data Science	3
CMSE 821	Numerical Methods for Differential Equations	3
CMSE 822	Parallel Computing	3
CMSE 823	Numerical Linear Algebra I	3
CSE 836	Probabilistic Models and Algorithms in Computational Biology	3
CSE 845	Multi-disciplinary Research Methods for the Study of Evolution	3
CSE 881	Data Mining	3
ECE 837	Computational Methods in Electromagnetics	3
ME 835	Turbulence Modeling and Simulation	3
ME 840	Computational Fluid Dynamics and Heat Transfer	3
ME 872	Finite Element Method	3
MTH 451	Numerical Analysis I	3
MTH 452	Numerical Analysis II	3

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MTH	850	Numerical Analysis I	3
MTH	851	Numerical Analysis II	3
MTH	852	Numerical Methods for Ordinary Differential Equations	3
MTH	950	Numerical Methods for Partial Differential Equations I	3
MTH	951	Numerical Methods for Partial Differential Equations II	3
MTH	995	Special Topics in Numerical Analysis and Operations Research	3 to 6
PHY	480	Computational Physics	3
PHY	915	Computational Condensed Matter Physics	2
PHY	919	Modern Electronic Structure Theory	2
PHY	950	Data Analysis Methods for High-Energy and Nuclear Physics	2
PHY	998	High Performance Computing and Computational Tools for Nuclear Physics	2
PLB	810	Theories and Practices in Bioinformatics	3
QB	826	Introduction to Quantitative Biology Techniques	1
STT	461	Computations in Probability and Statistics	3
STT	465	Bayesian Statistical Methods	3
STT	802	Statistical Computation	3
STT	874	Introduction to Bayesian Analysis	3

Courses used to fulfill requirement 1. may not be used to fulfill this requirement. Additional courses at the 400-level or above may be used to fulfill this requirement if approved by the CMSE graduate advisor. Students must have a minimum 3.0 grade-point average in courses applied to the certificate in order for it to be awarded.

### GRADUATE CERTIFICATE IN HIGH-PERFORMANCE COMPUTING

The Graduate Certificate in High-Performance Computing is intended for students with interest in applying computational and data science approaches that require parallel and/or high-performance computing to their research problems, or who generally desire broad training in parallel computational methodology.

#### Requirements for the Graduate Certificate in High-Performance Computing

			CREDITS
Students must complete a minimum of 9 credits from the following:			
1. The following core course (3 credits):			
CMSE 822	Parallel Computing		3
2. Two or more additional courses selected from the following:			
AST 911	Numerical Techniques in Astronomy		2
CEM 883	Computational Quantum Chemistry		3
CEM 888	Computational Chemistry		3
CSE 836	Probabilistic Models and Algorithms in Computational Biology		3
CSE 845	Multi-disciplinary Research Methods for the Study of Evolution		3
CSE 881	Data Mining		3
ECE 837	Computational Methods in Electromagnetics		3
ME 835	Turbulence Modeling and Simulation		3
ME 840	Computational Fluid Dynamics and Heat Transfer		3
ME 872	Finite Element Method		3
MTH 850	Numerical Analysis I		3
MTH 851	Numerical Analysis II		3
MTH 852	Numerical Methods for Ordinary Differential Equations		3
MTH 950	Numerical Methods for Partial Differential Equations I		3
MTH 951	Numerical Methods for Partial Differential Equations II		3
MTH 995	Special Topics in Numerical Analysis and Operations Research		3 to 6
PHY 915	Computational Condensed Matter Physics		2
PHY 919	Modern Electronic Structure Theory		2
PHY 950	Data Analysis Methods for High-Energy and Nuclear Physics		2
PHY 998	High Performance Computing and Computational Tools for Nuclear Physics		2
PLB 810	Theories and Practices in Bioinformatics		3
QB 826	Introduction to Quantitative Biology Techniques		1
STT 802	Statistical Computation		3
STT 874	Introduction to Bayesian Analysis		3

Additional courses at the 800-level or above may be used to fulfill this requirement if approved by the CMSE graduate advisor. Students must have a minimum 3.0 grade-point average in courses applied to the certificate in order for it to be awarded.

## DEPARTMENT of COMPUTER SCIENCE and ENGINEERING

**Abdol H. Esfahanian, Chairperson**

Computer science encompasses the broad areas of problem-solving and information processing using digital computers. Students learn to analyze, design and build integrated software and hardware systems that process, transmit, and reason about information to solve problems. Graduates of the Computer Science and Computational Data Science programs are employed in essentially all areas of industry, government, and education. They serve as project managers, designers, analysts, and developers involved with problems in commercial software development, data analysis, business and research, process and production control software systems, and computer components and systems.

### UNDERGRADUATE PROGRAMS

The Department of Computer Science and Engineering offers two Bachelor of Science degree programs, one in Computer Science and one in Computational Data Science. Students in both programs are provided with a theoretical foundation in computer science, required for continued success in these rapidly changing fields, as well as practical experience with current tools and techniques. To achieve these goals, students take courses that span a spectrum of knowledge ranging from theoretical foundations, which enable a rigorous analysis of data and computational problems and solutions, to applied design and engineering methods. At the upper level, students choose from a wide range of elective courses focusing on computer networks, big data, artificial intelligence, database systems, computer security, software engineering, and computer graphics. The senior year in both programs culminates with a team-oriented design course building on much of what one has learned throughout the undergraduate experience. Students with interests in other areas can consult and work with interested faculty from a wide range of academic disciplines.

The Bachelor of Science in Computer Science prepares students to be professionals in software design and development. The Bachelor of Science in Computational Data Science prepares students for careers where the central focus is manipulating and deriving understanding from large volumes of data.

## COLLEGE OF ENGINEERING

### COMPUTATIONAL DATA SCIENCE

The Bachelor of Science degree in Computational Data Science focuses on the computational foundations of data science, providing an in-depth understanding of the algorithms and data structures for storing, manipulating, visualizing, and learning from large data sets. Students in the program have unique access to a wide range of fundamental computer science courses in topics ranging from mobile application and web development to theory of computation and fundamental algorithms. Students can tailor their degree to their unique interests and requirements, with an emphasis on computational foundations.

#### Requirements for the Bachelor of Science Degree in Computational Data Science

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 120 credits, including general elective credits, are required for the Bachelor of Science degree in Computational Data Science.

The University's Tier II writing requirement for the Computational Data Science major is met by completing Computational Mathematics, Science and Engineering 495, referenced in item 3. b. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

##### a. Bioscience (4 to 6 credits)

- (1) One of the following courses:

BS	161	Cell and Molecular Biology	3
ENT	205	Pests, Society and Environment	3
IBIO	150	Integrating Biology: From DNA to Populations	3
MMG	141	Introductory Human Genetics	3
MMG	201	Fundamentals of Microbiology	3
PLB	105	Plant Biology	3
PSL	250	Introductory Physiology	4

- (2) One of the following courses:

BS	171	Cell and Molecular Biology Laboratory	2
CEM	161	Chemistry Laboratory I	1
CEM	162	Chemistry Laboratory II	1
PHY	191	Physics Laboratory for Scientists, I	1
PHY	192	Physics Laboratory for Scientists, II	1
PLB	106	Plant Biology Laboratory	1

- b. All of the following courses (47 credits):

CMSE	201	Computational Modeling and Data Analysis I	4
CMSE	381	Fundamentals of Data Science Methods	4
CMSE	382	Optimization Methods in Data Science	4
CMSE	495	Experiential Learning in Data Science (W)	4
CSE	232	Introduction to Programming II	4
CSE	300	Social, Ethical, and Professional Issues in Computing	1
CSE	331	Algorithms and Data Structures	3
CSE	380	Information Management and the Cloud	3
CSE	404	Introduction to Machine Learning	3
CSE	482	Big Data Analysis	3
CSE	480	Database Systems	3
MTH	314	Matrix Algebra with Computational Applications	3
STT	180	Introduction to Data Science	4
STT	380	Probability and Statistics for Data Science	4

- c. Two courses selected from the following (6 credits):

CSE	402	Biometrics and Pattern Recognition	3
CSE	415	Introduction to Parallel Computing	3
CSE	431	Algorithm Engineering	3
CSE	440	Introduction to Artificial Intelligence	3

Computer Science and Engineering 415 and Computational Science, Mathematics and Engineering 401 may not be used to fulfill both requirements c. and d.

- d. Two courses selected from the following (6 credits):

CMSE	401	Methods for Parallel Computing	4
CMSE	402	Data Visualization Principles and Techniques	3
CSE	402	Biometrics and Pattern Recognition	3
CSE	415	Introduction to Parallel Computing	3
CSE	431	Algorithm Engineering	3
CSE	440	Introduction to Artificial Intelligence	3
CSE	471	Media Processing and Multimedia Computing	3
CSE	472	Computer Graphics	3
MTH	451	Numerical Analysis I	3
MTH	468	Predictive Analytics	3
STT	464	Statistics for Biologists	3
STT	465	Bayesian Statistical Methods	3

Computer Science and Engineering 415 and Computational Science, Mathematics and Engineering 401 may not be used to fulfill both requirements c. and d.

### COMPUTER SCIENCE

The Bachelor of Science degree in Computer Science focuses on the analysis, design, and development of software and hardware computer systems. Computer Science applies creativity, logic, and computational thinking to solve problems important to science, healthcare, education, business, entertainment, government, and all aspects of modern life. Students develop the fundamental programming skills for building software systems and are introduced to a wide range of algorithms, data structures, and patterns that can be applied to problem-solving. A range of elective courses allows a student to customize the degree in this expansive field to their interests. Complementing these major areas, the cognate provides an excellent opportunity to develop an individually selected area of interest.

Students who are enrolled in the Bachelor of Science degree program with a major in computer science may elect a Minor in Game Design and Development. For additional information, refer to the *Minor in Game Design and Development* statement in the *Department of Media and Information* section of this catalog.

The Bachelor of Science degree program in Computer Science is accredited by the Computing Accreditation Commission of ABET, [www.abet.org](http://www.abet.org) under the General Criteria and the *Computer Science and Similarly Named Computing Programs Program Criteria*.

#### Requirements for the Bachelor of Science Degree in Computer Science

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 120 credits, including general elective credits, are required for the Bachelor of Science degree in Computer Science.

The University's Tier II writing requirement for the Computer Science major is met by completing Computer Science and Engineering 498, referenced in item 3. b. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

CREDITS



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- a. **Bioscience** - Courses may not be used to satisfy both (1) and (2) below 4 to 6
- (1) One of the following courses:
- |          |  |   |
|----------|--|---|
| BS 161   | Cell and Molecular Biology                   | 3 |
| ENT 205  | Pests, Society and Environment               | 3 |
| IBIO 150 | Integrating Biology: From DNA to Populations | 3 |
| MGI 141  | Introductory Human Genetics                  | 3 |
| MGI 201  | Fundamentals of Microbiology                 | 3 |
| PLB 105  | Plant Biology                                | 3 |
| PSL 250  | Introductory Physiology                      | 4 |
- (2) One of the following courses:
- |         |                                       |   |
|---------|---------------------------------------|---|
| BS 171  | Cell and Molecular Biology Laboratory | 2 |
| CEM 161 | Chemistry Laboratory I                | 1 |
| CEM 162 | Chemistry Laboratory II               | 1 |
| PHY 191 | Physics Laboratory for Scientists, I  | 1 |
| PHY 192 | Physics Laboratory for Scientists, II | 1 |
| PLB 106 | Plant Biology Laboratory              | 1 |
- b. All of the following courses (32 credits):
- |         |   |   |
|---------|---|---|
| CSE 232 | Introduction to Programming II                        | 4 |
| CSE 260 | Discrete Structures in Computer Science               | 4 |
| CSE 300 | Social, Ethical, and Professional Issues in Computing | 1 |
| CSE 320 | Computer Organization and Architecture                | 3 |
| CSE 325 | Computer Systems                                      | 3 |
| CSE 331 | Algorithms and Data Structures                        | 3 |
| CSE 335 | Object-Oriented Software Design                       | 4 |
| CSE 380 | Information Management and the Cloud                  | 3 |
| CSE 498 | Collaborative Design (W)                              | 4 |
| STT 351 | Probability and Statistics for Engineering            | 3 |
- Students must have a minimum grade of 2.0 in each of the following courses: CSE 300, CSE 320, CSE 325, CSE 331, CSE 335, CSE 380.
- c. One of the following courses (3 or 4 credits):
- |          |  |   |
|----------|--|---|
| MTH 314  | Matrix Algebra with Computational Applications | 3 |
| MTH 317H | Honors Linear Algebra                          | 4 |
- d. An additional five courses selected from the following (15 credits):
- |         |  |        |
|---------|--|--------|
| CSE 402 | Biometrics and Pattern Recognition           | 3      |
| CSE 404 | Introduction to Machine Learning             | 3      |
| CSE 410 | Operating Systems                            | 3      |
| CSE 415 | Introduction to Parallel Programming         | 3      |
| CSE 420 | Computer Architecture                        | 3      |
| CSE 422 | Computer Networks                            | 3      |
| CSE 425 | Introduction to Computer Security            | 3      |
| CSE 431 | Algorithm Engineering                        | 3      |
| CSE 434 | Autonomous Vehicles                          | 3      |
| CSE 435 | Software Engineering                         | 3      |
| CSE 440 | Introduction to Artificial Intelligence      | 3      |
| CSE 450 | Translation of Programming Languages         | 3      |
| CSE 460 | Computability and Formal Language Theory     | 3      |
| CSE 471 | Media Processing and Multimedia Computing    | 3      |
| CSE 472 | Computer Graphics                            | 3      |
| CSE 476 | Mobile Application Development               | 3      |
| CSE 477 | Web Application Architecture and Development | 3      |
| CSE 480 | Database Systems                             | 3      |
| CSE 482 | Big Data Analysis                            | 3      |
| CSE 491 | Selected Topics in Computer Science          | 1 to 4 |
| MTH 451 | Numerical Analysis I                         | 3      |
- e. **Required Cognate** (12 credits):
- Cognates in the following areas are available to students in Computer Science: business, communication arts and sciences, foreign language, mathematics, the natural sciences, philosophy, psychology, the social sciences, and telecommunication. Students may complete cognates in other areas with the approval of the Department of Computer Science and Engineering academic advisor. The cognate should enhance the student's ability to apply analytical procedures in a specific subject area.
- The cognate requires a minimum of four courses totaling 12 or more credits outside the College of Engineering selected from (1) or (2) below. The academic advisor of the Department of Computer Science and Engineering must preapprove both the cognate and the cognate courses.
- (1) A minimum of four courses totaling 12 or more credits. At least 6 of the 12 credits must be in courses at the 300-400 level.
- (2) Cognate in The Eli Broad College of Business consisting of this specific set of courses: ACC 230, FI 320, GBL 323 and MKT 327.
- (3) A sequence of at least three courses in a foreign language totaling at least 12 credits.

## Concentrations in Computer Science

The Department offers the following concentrations to students wishing an area of specialization in their degree. The concentrations are available to, but not required of, any student enrolled in the Bachelor of Science degree program in Computer Science. NOTE: Completing the Bachelor of Science degree in Computer Science with a concentration may require more than 120 credits. Upon completion of the required courses for a concentration, certification will appear on the student's official transcript. Students may select no more than one concentration.

For any concentration, 3 credits of CSE 499 Undergraduate Research related to the subject area may be applied with approval of the Department of Computer Science and Engineering.

### Artificial Intelligence

To complete a Bachelor of Science degree in Computer Science with an artificial intelligence concentration, students must complete the requirements for the bachelor's degree, including the following:

Two of the following courses (6 credits):

CSE 404	Introduction to Machine Learning	3
CSE 440	Introduction to Artificial Intelligence	3
CSE 482	Big Data Analysis	3

Three of the following courses not taken above (9 to 12 credits):

CSE 402	Biometrics and Pattern Recognition	3
CSE 404	Intro to Machine Learning	3
CSE 434	Autonomous Vehicles	3
CSE 440	Introduction to Artificial Intelligence	3
CSE 482	Big Data Analysis	3
CSE 803	Computer Vision	3
ADV 401	Neuromarketing and Consumer Decisions	3
LIN 401	Introduction to Linguistics	4
LIN 424	Introduction to Phonetics and Phonology	3
LIN 427	Laboratory Phonetics	3
LIN 431	Introduction to Morphology	3
LIN 434	Introduction to Syntax	3
LIN 437	Introduction to Semantics and Pragmatics	3
LIN 463	Introduction to Cognitive Science	3
LIN 471	Sociolinguistics	3
MI 484	Human Robot Interaction (W)	3
MTH 468	Predictive Analysis	3
NEU 301	Introduction to Neuroscience I	3
NEU 302	Introduction to Neuroscience II	3
PHL 330	Formal Deductive Reasoning	4
PHL 331	Formal Practical Reasoning	4
PHL 432	Logic and its Metatheory	4
PSY 301	Cognitive Neuroscience	3

### Computer Systems

To complete a Bachelor of Science degree in Computer Science with a computer systems concentration, students must complete the requirements for the bachelor's degree, including the following:

All of the following courses (9 credits):

CSE 410	Operating Systems	3
CSE 422	Computer Networks	3
CSE 450	Translation of Programming Languages	3

Two of the following courses (6 credits):

CSE 415	Introduction to Parallel Programming	3
CSE 420	Computer Architecture	3
CSE 425	Introduction to Computer Security	3
CSE 434	Autonomous Vehicles	3
CSE 472	Computer Graphics	3
CSE 480	Database Systems	3

## COLLEGE OF ENGINEERING

### Cybersecurity

To complete a Bachelor of Science degree in Computer Science with a cybersecurity concentration, students must complete the requirements for the bachelor's degree, including the following:

All of the following courses (6 credits):

CSE 402	Biometrics and Pattern Recognition	3
CSE 425	Introduction to Computer Security	3
Three of the following courses (9 credits):		
CSE 410	Operating Systems	3
CSE 422	Computer Networks	3
CSE 431	Algorithm Engineering	3
CSE 434	Autonomous Vehicles	3
CSE 480	Database Systems	3
CSE 482	Big Data Analysis	3
MI 239	Digital Footprints: Privacy and Online Behavior	3
MTH 416	Introduction to Algebraic Coding	3

### Multimedia and Graphics

To complete a Bachelor of Science degree in Computer Science with a multimedia and graphics concentration, students must complete the requirements for the bachelor's degree, including the following:

Two of the following courses (6 credits):

CSE 471	Media Processing and Multimedia Computing	3
CSE 472	Computer Graphics	3
CSE 476	Mobile Application Development	3
CSE 477	Web Application Architecture and Development	3

Three of the following courses not taken above (8 or 9 credits):

CSE 471	Media Processing and Multimedia Computing	3
CSE 472	Computer Graphics	3
CSE 476	Mobile Application Development	3
CSE 477	Web Application Architecture and Development	3
CSE 803	Computer Vision	3
CMSE402	Data Visualization Principles and Techniques	3
FLM 230	Introduction to Film	3
FLM 260	Introduction to Digital Film and Emergent Media	3
MI 231	Game and Interactive Media Development	3
MI 247	Three-Dimensional Graphics and Design	3
MI 347	Advanced Three-Dimensional Computer Animation	3
MI 350	Evaluating Human-Centered Technology	3
MI 377	Advanced 3D Modeling	3
MI 445	Game Design and Development I	3
MI 450	Creating Human-Centered Technology	3
MI 455	Game Design and Development II	3
MI 462	Social Media and Social Computing	3
MI 482	Building Virtual Worlds (W)	3
MI 497	Game Design Studio	3
STA 380	Electronic Art	3
STA 384	Experiments in Digital Video	3
THR 205	Media Acting I	2
THR 337	Compositing and Special Effects for Stage and Screen	3
THR 419	Projection Design for Live Performance	3

### Software Engineering

To complete a Bachelor of Science degree in Computer Science with a software engineering concentration, students must complete the requirements for the bachelor's degree, including the following:

The following course (3 credits):

CSE 435	Software Engineering	3
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Four of the following courses (12 credits):

CSE 431	Algorithm Engineering	3
CSE 476	Mobile Application Development	3
CSE 477	Web Application Architecture and Development	3
CSE 480	Database Systems	3
CSE 870	Advanced Software Engineering	3
MI 350	Evaluating Human-Centered Technology	3
MI 420	Interactive Prototyping	3
MI 450	Creating Human-Centered Technology (W)	3

### Theory

To complete a Bachelor of Science degree in Computer Science with a theory concentration, students must complete the requirements for the bachelor's degree, including the following:

The following course (3 credits):

CSE 460	Computability and Formal Language Theory	3
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One of the following courses (3 credits):

CSE 431	Algorithm Engineering	3
CSE 830	Design and Theory of Algorithms	3

Three of the following courses (9 or 10 credits):

CSE 835	Algorithmic Graph Theory	3
CSE 860	Foundations of Computing	3
MTH 299	Transitions 4	
MTH 416	Introduction to Algebraic Coding	3
MTH 417	Topics in Number Theory	3
MTH 880	Combinatorics I	3
MTH 882	Combinatorics II	3

## MINOR IN COMPUTER SCIENCE

The Minor in Computer Science and Engineering is administered by the Department of Computer Science and Engineering. This minor will provide students with a foundation in computer science that applies to many disciplines. This will also provide opportunities for students in industry or government, as well as prepare students for graduate-level study in computer science.

The minor is available as an elective to students who are enrolled in bachelor's degree programs at Michigan State University other than the Bachelor of Science Degree in Computer Science or the Bachelor of Science Degree in Computer Engineering or the Bachelor of Science Degree in Computational Data Science, or the Bachelor of Science Degree in Data Science. With the approval of the department and college that administers the student's degree program, the courses that are used to satisfy the minor may also be used to satisfy the requirements for the bachelor's degree.

Students who plan to complete the requirements for the minor must apply to the Department of Computer Science and Engineering. The minimum criteria for acceptance are the completion of Computer Science and Engineering 231 and 260 with a combined grade-point average in those two courses of 3.0. Enrollment may be limited. Application forms are available at [www.cse.msu.edu](http://www.cse.msu.edu).

### Requirements for the Minor in Computer Science

Complete a minimum of 18 credits in the Department of Computer Science and Engineering from the following:

	CREDITS
1. All of the following courses (13 credits):	
CSE 231 Introduction to Programming I	4
CSE 232 Introduction to Programming II	4
CSE 260 Discrete Structures in Computer Science	4
CSE 300 Social, Ethical, and Professional Issues in Computing	1
2. Two of the following courses (6 or 7 credits):	
CSE 320 Computer Organization and Architecture	3
CSE 325 Computer Systems	3
CSE 331 Algorithms and Data Structures	3
CSE 335 Object-Oriented Software Design	4
CSE 380 Information Management and the Cloud	3
CSE 402 Biometrics and Pattern Recognition	3
CSE 404 Introduction to Machine Learning	3
CSE 420 Computer Architecture	3
CSE 431 Algorithm Engineering	3
CSE 434 Autonomous Vehicles	3
CSE 440 Introduction to Artificial Intelligence	3
CSE 460 Computability and Formal Language Theory	3
CSE 471 Media Processing and Multimedia Computing	3
CSE 472 Computer Graphics	3
CSE 476 Mobile Application Development	3
CSE 477 Web Application Architecture and Development	3
CSE 480 Database Systems	3
CSE 482 Big Data Analysis	3

## COLLEGE OF ENGINEERING

### GRADUATE STUDY

The Department of Computer Science and Engineering offers programs leading to the Master of Science and Doctor of Philosophy degrees. Advanced study is available in a variety of computer science research areas such as algorithms, computer security, databases, data mining, machine learning, natural language processing, networking, pattern recognition and image processing, and software engineering, as well as many interdisciplinary research areas such as bioinformatics, cognitive science, and digital evolution.

Students who are enrolled in master's or doctoral degree programs in the Department of Computer Science and Engineering may elect an Interdepartmental Specialization in Cognitive Science. For additional information, refer to the statement on *Interdepartmental Graduate Specializations in Cognitive Science* in the *College of Social Science* section of this catalog. For additional information, contact the Department of Computer Science and Engineering.

### COMPUTER SCIENCE

#### Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### Admission

Applicants for admission should possess a bachelor's degree in computer science or a related field such as mathematics, physics, or electrical engineering. All applicants are encouraged to submit their scores from the Graduate Record Examination (GRE) General Test. Additional information is available on the Department's Web site at <http://cse.msu.edu>.

#### Requirements for the Master of Science Degree in Computer Science

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis) and meet the requirements specified below:

##### Requirements for Both Plan A and Plan B:

The student must complete a minimum of 18 credits in courses listed below with at least one course from each breadth area:

##### System Design and Analysis

CSE 812	Distributed Systems	3
CSE 820	Advanced Computer Architecture	3
CSE 822	Parallel Computing	3
CSE 824	Advanced Computer Networks and Communications	3
CSE 825	Computer and Network Security	3
CSE 834	Advanced Topics in Automated Vehicles	3
CSE 893	Selected Topics in System Design and Analysis	3
CSE 870	Advanced Software Engineering	3

##### Theory and Algorithms

CSE 814	Computer Aided Verification	3
CSE 830	Design and Theory of Algorithms	3
CSE 835	Algorithmic Graph Theory	3
CSE 860	Foundations of Computing	3
CSE 894	Selected Topics in Theory and Algorithms	3

##### Data Analysis and Applications

CSE 802	Pattern Recognition and Analysis	3
CSE 803	Computer Vision	3
CSE 840	Computational Foundations in Artificial Intelligence	3
CSE 841	Artificial Intelligence	3

CSE 842	Natural Language Processing	3
CSE 845	Multidisciplinary Research Methods for the Study of Evolution	3
CSE 847	Machine Learning	3
CSE 849	Deep Learning	3
CSE 848	Evolutionary Computation	3
CSE 881	Data Mining	3

#### Additional Requirements for Plan A:

The student must complete:

1. A minimum of 21 credits in 800-900 level courses chosen in consultation with the student's advisor, excluding Computer Science and Engineering 801, 890, 898, and 899.
2. Complete 6 credits of CSE 899 Master's Thesis Research.

#### Additional Requirements for Plan B:

1. Complete a minimum of 24 credits in 800-900 level courses chosen in consultation with the student's advisor, excluding Computer Science 801, 890, 898, and 899.

### Doctor of Philosophy

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### Admission

Applicants should be in the top 25 percent of their master's degree classes and should have a grade-point average of at least 3.50 on a scale of 4.0.

Applicants are encouraged to submit their scores on the Graduate Record Examination General Test.

Applicants who have a Bachelor of Science degree and who demonstrate exceptional potential for graduate study may be accepted for admission to the doctoral program.

Additional information is available on the Department's Web site at <http://cse.msu.edu>.

#### Requirements for the Doctor of Philosophy Degree in Computer Science

1. Students must complete a minimum of 30 credits beyond the research requirements in CSE 999. Students must maintain a cumulative grade-point average of at least 3.00 in all courses counted towards the 30 credits. The student's guidance committee reserves the right to require additional course work beyond the minimum. Students should contact the graduate director for approval of any courses outside the Department of Computer Science and Engineering.
2. Students may receive credit for 24 credits of course work taken during a prior completed Master of Science degree or equivalent. In the case where the master's degree was obtained from the Department of Computer Science and Engineering at Michigan State University, the Ph.D. student is only required to complete 24 to 36 credits of CSE 999 Doctoral Dissertation Research.
3. As part of the total credit requirements, students must complete a minimum of 18 credits in courses listed below with at least one course from each breadth area. If a student has completed a Master of Science degree and receives a waiver, then the corresponding breadth area requirement will also be waived.

##### System Design and Analysis

CSE 812	Distributed Systems	3
CSE 820	Advanced Computer Architecture	3
CSE 822	Parallel Computing	3
CSE 824	Advanced Computer Networks and Communications	3
CSE 825	Computer and Network Security	3
CSE 834	Advanced Topics in Automated Vehicles	3
CSE 870	Advanced Software Engineering	3
CSE 893	Selected Topics in System Design and Analysis	3

##### Theory and Algorithms

CSE 814	Computer Aided Verification	3
CSE 830	Design and Theory of Algorithms	3

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CSE 835	Algorithmic Graph Theory	3
CSE 860	Foundations of Computing	3
CSE 894	Selected Topics in Theory and Algorithms	3
<b>Data Analysis and Applications</b>		
CSE 802	Pattern Recognition and Analysis	3
CSE 803	Computer Vision	3
CSE 840	Computational Foundations in Artificial Intelligence	3
CSE 841	Artificial Intelligence	3
CSE 842	Natural Language Processing	3
CSE 845	Multidisciplinary Research Methods for the Study of Evolution	3
CSE 847	Machine Learning	3
CSE 848	Evolutionary Computation	3
CSE 849	Deep Learning	3
CSE 850	Advanced Topics in Adversarial Machine Learning	3
CSE 851	Genetic Programming	3
CSE 850	Advanced Topics in Adversarial Machine Learning	3
CSE 851	Genetic Programming	3
CSE 881	Data Mining	3
CSE 895	Selected Topics in Data Analysis and Applications	3
4.	Complete a minimum of 24 credits in 800-900 level courses chosen in consultation with the student's advisor, excluding Computer Science 801, 890, 898, and 899.	
5.	Pass a qualifying examination consisting of a written and an oral part, generally within two years of beginning the Ph.D. program.	
6.	Pass the comprehensive examination that includes a program statement presenting the student's learning and professional background and goals, and provides a rationale for the students declared focus areas.	
7.	Complete 24 credits of CSE 999 Doctoral Dissertation Research and successfully defend the dissertation. Present the results of the research in a public seminar during the final oral examination.	

## DEPARTMENT of ELECTRICAL and COMPUTER ENGINEERING

**Nelson Sepulveda Alancastro, Chairperson**

The Department of Electrical and Computer Engineering offers two undergraduate programs and a concentration leading to a Bachelor of Science degree. The computer engineering program provides students the opportunity to customize their program through core electives in computer architecture, computer networks, and VLSI design and focus electives in hardware or software tracks. The program in electrical engineering allows students to choose their major electives from seven areas: electromagnetics, power, integrated circuits/VLSI, solid-state electronics/electro-optics, communications/signal processing, control/robotics, and biomedical engineering. In addition, a student in either program can choose a biomedical engineering concentration that is noted on the student's transcript.

### UNDERGRADUATE PROGRAMS

#### COMPUTER ENGINEERING

Computer engineering is concerned with the organization and design of computers and computer systems. The study of computer hardware and software, and their integration and application, is emphasized. The undergraduate program in computer engineering integrates studies in mathematics, basic sciences, engineering sciences, and engineering

design. The program is structured to establish analytical and design skills in areas such as computer architecture, digital logic design, analog and mixed-signal circuits, computer communication networks, digital computer control, integrated circuit engineering, software engineering, operating systems, data structures and algorithms, computer-aided engineering, and electronic design automation. Complementing these fundamentals, the program also provides opportunities for specialization in individually selected areas of interest.

The Bachelor of Science Degree program in Computer Engineering is accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org).

#### Requirements for the Bachelor of Science Degree in Computer Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Computer Engineering.

The University's Tier II writing requirement for the Computer Engineering major is met by completing Electrical and Computer Engineering 480. That course is referenced in item 3. c. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

	CREDITS
a. One of the following courses (1 credit):	
CEM 161 Chemistry Laboratory I	1
PHY 191 Physics Laboratory for Scientists, I	1
b. All of the following courses (39 credits):	
CSE 232 Introduction to Programming II	4
CSE 260 Discrete Structures in Computer Science	4
CSE 325 Computer Systems	3
CSE 331 Algorithms and Data Structures	3
ECE 201 Circuits and Systems I	3
ECE 202 Circuits and Systems II	3
ECE 203 Electric Circuits and Systems Laboratory	1
ECE 230 Digital Logic Fundamentals	3
ECE 280 Electrical Engineering Analysis	3
ECE 302 Electronic Circuits	3
ECE 303 Electronics Laboratory	1
ECE 331 Microprocessors and Digital Systems	4
ECE 366 Introduction to Signal Processing	3
ECE 390 Ethics, Professionalism and Contemporary Issues	1
c. One of the following courses (4 credits):	
ECE 480 Senior Design	4
ECE 489 Independent Senior Design	4
d. <b>Electives</b>	

Complete 21 credits of electives as specified below. At least 15 credits must be from the focus tracks below including at least 6 credits from the core, with at least one course with a laboratory. Additional credits to meet the 21 credit requirement may be taken from other courses listed below, any 400-level Computer Science and Engineering (CSE) or Electrical and Computer Engineering (ECE) courses, or by completing an approved 3 or 4 credit experiential, out-of-classroom education experience obtained through engineering cooperative education or independent study.

#### Focus Tracks

##### Core

At least 6 credits from the following:

CSE 335	Object-Oriented Software Design	4
CSE 420	Computer Architecture	3
CSE 422	Computer Networks	3
or		
ECE 442	Introduction to Communication Networks	3

## COLLEGE OF ENGINEERING

CSE 425	Introduction to Computer Security	3
or		
ECE 456	Introduction to Communication and Network Security	3
ECE 430	Embedded Cyber-Physical Systems	4
Both CSE 422 and ECE 442 or CSE 425 and ECE 456 may not be used to fulfill this requirement.		
<b>Hardware</b>		
ECE 410	VLSI Design	4
ECE 411	Electronic Design Automation	4
ECE 431	Smart Sensor Systems	3
ECE 445	Biomedical Instrumentation	3
<b>Software Systems</b>		
CSE 410	Operating Systems	3
CSE 415	Introduction to Parallel Programming	3
CSE 431	Algorithm Engineering	3
CSE 435	Software Engineering	3
CSE 450	Translation of Programming Languages	3
CSE 476	Mobile Application Development	3
CSE 480	Database Systems	3
<b>Intelligent Systems</b>		
CSE 404	Introduction to Machine Learning	3
CSE 440	Introduction to Artificial Intelligence	3
CSE 482	Big Data Analysis	3
ECE 434	Autonomous Vehicles	3
ECE 446	Biomedical Signal Processing	3
ECE 466	Digital Signal Processing and Filter Design	3
MTH 314	Matrix Algebra with Computational Applications	3
STT 351	Probability and Statistics for Engineering	3
<b>Electrical Systems</b>		
ECE 305	Electromagnetic Fields and Waves I	4
ECE 313	Control Systems	3
ECE 377	Principles of Electronic Devices	3
ECE 404	Radio Frequency Electronic Circuits	4
ECE 417	Robotics	4

### Concentrations

The department offers the following concentrations to students wishing an area of specialization in their degree. Concentrations are available to, but not required of, any student enrolled in the Bachelor of Science Degree in Computer Engineering. Courses completed to satisfy requirement 3 above may also be used to satisfy the requirements of a concentrations. NOTE: Completing the Bachelor of Science degree in Computer Engineering with a concentration may require more than 128 credits. Upon completion of the required courses for a concentration, certification will appear on the student's official transcript.

#### Biomedical Engineering

This concentration is for students who plan to pursue graduate work in biomedical areas or seek employment in selected medical-related areas. To earn a Bachelor of Science degree in Computer Engineering with a biomedical engineering concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. Complete 6 credits from the following courses:	
ANTR350 Human Gross Anatomy for Pre-Health Professionals	3
BS 161 Cell and Molecular Biology	3
PSL 250 Introductory Physiology	4
PSL 310 Physiology for Pre-Health Professionals	4
2. Complete 9 credits from the following courses:	
BE 444 Biosensors for Medical Diagnostics	3
ECE 445 Biomedical Instrumentation	3
ECE 446 Biomedical Signal Processing	3
ECE 447 Introduction to Biomedical Imaging	3
ECE 448 Modeling and Analysis of Bioelectrical Systems	3
ECE 449 Fundamentals of Acoustics	3

Students may enroll in 3 or 4 credits of ECE 490 or 491 with biomedical engineering content as approved by the student's advisor for partial fulfillment of this requirement.

#### Cybersecurity

This concentration is for students interested in the theory and practice of communication networks and security. To earn a Bachelor of Science degree in Computer Engineering with a cybersecurity concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. All of the following courses (9 credits):	
ECE 442 Introduction to Communication Networks	3
ECE 456 Introduction to Communication and Network Security	3
ECE 457 Communication Systems	3
2. Two of the following courses (6 credits):	
CSE 402 Biometrics and Pattern Recognition	3
CSE 410 Operating Systems	3
CSE 425 Introduction to Computer Security	3
CSE 482 Big Data Analysis	3

#### Robotics and Automation

This concentration is for students interested in graduate work or employment in robotics or automation areas. To earn a Bachelor of Science degree in Computer Engineering with a robotics and automation concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. The following course:	
ECE 417 Robotics	4
2. Complete 9 credits from the following:	
ECE 415 Computer Aided Manufacturing	3
ECE 416 Digital Control	3
ECE 430 Embedded Cyber-Physical Systems	4
ECE 431 Smart Sensors Systems	3
ECE 434 Autonomous Vehicles	3
ECE 466 Digital Signal Processing	3

#### Smart Systems

This concentration is for students interested in the design and implementation of smart devices and systems for graduate work or employment in consumer electronics, wearables, and internet of things (IoT) fields. To earn a Bachelor of Science degree in Computer Engineering with a smart systems concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. Complete at least 13 credits from the following:	
CSE 404 Introduction to Machine Learning	3
CSE 420 Computer Architecture	3
CSE 440 Introduction Artificial Intelligence	3
CSE 476 Mobile Application Development	3
CSE 482 Big Data Analysis	3
ECE 410 VLSI Design	4
ECE 411 Electronic Design Automation	4
ECE 430 Embedded Cyber-Physical Systems	4
ECE 431 Smart Sensors Systems	3
ECE 445 Biomedical Instrumentation	3
ECE 466 Digital Signal Processing	3

#### Software Systems

This concentration is for students wishing to focus on software development for graduate work or employment in embedded systems, cloud services and other software intensive fields. To earn a Bachelor of Science degree in Computer Engineering with a software systems concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. Complete at least 13 credits from the following:	
CSE 410 Operating Systems	3
CSE 415 Introduction to Parallel Programming	3
CSE 435 Software Engineering	3
CSE 450 Translation of Programming Languages	3
CSE 476 Mobile Application Development	3
ECE 430 Embedded Cyber-Physical Systems	4

## COLLEGE OF ENGINEERING

### ELECTRICAL ENGINEERING

The program provides both required and elective studies in communications, computers, control systems, electromagnetics, electronics, materials processing, power, signals, solid state, and biomedical engineering. It places emphasis on the fundamentals of science and mathematics and their application to the solution of contemporary problems that are within the purview of professional electrical engineers. The program is designed to establish a sound scientific basis for continuous growth in professional competence.

The Bachelor of Science Degree program in Electrical Engineering is accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org).

#### Requirements for the Bachelor of Science Degree in Electrical Engineering

1. The University requirements for bachelor's degrees as described in the Undergraduate *Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Electrical Engineering.

The University's Tier II writing requirement for the Electrical Engineering major is met by completing Electrical and Computer Engineering 480. That course is referenced in item 3. c. below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

#### CREDITS

- a. One of the following courses (1 credit):
 

CEM 161	Chemistry Laboratory I	1
PHY 191	Physics Laboratory for Scientists, I	1
- b. All of the following courses (38 credits):
 

ECE 201	Circuits and Systems I	3
ECE 202	Circuits and Systems II	3
ECE 203	Electric Circuits and Systems Laboratory	1
ECE 230	Digital Logic Fundamentals	3
ECE 280	Electrical Engineering Analysis	3
ECE 302	Electronic Circuits	3
ECE 303	Electronics Laboratory	1
ECE 305	Electromagnetic Fields and Waves I	4
ECE 313	Control Systems	3
ECE 320	Energy Conversion and Power Electronics	3
ECE 331	Microprocessors and Digital Systems	4
ECE 366	Introduction to Signal Processing	3
ECE 377	Principles of Electronic Devices	3
ECE 390	Ethics, Professionalism and Contemporary Issues	1
- c. One of the following courses (4 credits):
 

ECE 480	Senior Design	4
ECE 489	Independent Senior Design	4
- d. Complete a minimum of 18 credits including at least 12 credits from the focus areas below. The 12 credits must include at least one laboratory course (ECE 402, 404, 405, 407, 410, 415, 417, 420, 430, 431, 445, 458, 476, 477) and at least one 3 or 4 credit course from two different focus areas. Additional credits to meet the 18 credit requirement may be taken from MTH 314, any 400-level engineering course or by completing an approved 3 or 4 credit experiential education experience obtained in a minimum of three out-of-classroom experiences through engineering cooperative education or independent study. Students interested in the experiential education experience must contact the department for approval. Courses at the 400-level outside of Electrical and Computer Engineering may have restrictions or require additional prerequisites not included within this degree program.

#### Computing and Electronics

ECE 410	VLSI Design	4
ECE 430	Embedded Cyber-Physical Systems	4
ECE 431	Smart Sensor Systems	3
ECE 434	Autonomous Vehicles	3
ECE 442	Introduction to Communication Networks	3
ECE 445	Biomedical Instrumentation	3
ECE 456	Introduction to Communication and Network Security	3

#### Electrosiences

ECE 404	Radio Frequency Electronic Circuits	4
ECE 405	Electromagnetic Fields and Waves II	4
ECE 407	Electromagnetic Compatibility	4
ECE 447	Introduction to Biomedical Imaging	3
ECE 449	Fundamentals of Acoustics	3
ECE 476	Electro-Optics	4
ECE 477	Microelectronic Fabrication	3

#### Systems

ECE 415	Computer Aided Manufacturing	3
ECE 416	Digital Control	3
ECE 417	Robotics	4
ECE 420	Machines and Power Laboratory	1
ECE 423	Power System Analysis	3
ECE 424	Electrical Drives	3
ECE 425	Solid State Power Conversion	3
ECE 446	Biomedical Signal Processing	3
ECE 448	Modeling and Analysis of Bioelectrical Systems	3
ECE 457	Communication Systems	3
ECE 458	Communication Systems Laboratory	1
ECE 466	Digital Signal Processing	3

### Concentrations

The department offers the following concentrations to students wishing an area of specialization in their degree. Concentrations are available to, but not required of, any student enrolled in the Bachelor of Science Degree in Electrical Engineering. Courses completed to satisfy requirement 3. above may also be used to satisfy the requirements of a concentrations. NOTE: Completing the Bachelor of Science degree in Electrical Engineering with a concentration may require more than 128 credits. Upon completion of the required courses for a concentration, certification will appear on the student's official transcript.

#### Biomedical Engineering

This concentration is for students who plan to pursue graduate work in biomedical areas or seek employment in selected medical-related areas. To earn a Bachelor of Science degree in Electrical Engineering with a biomedical engineering concentration, students must complete requirements 1., 2., and 3. above and the following:

#### CREDITS

1. Complete 6 credits from the following courses:
 

ANTR350	Human Gross Anatomy for Pre-Health Professionals	3
BS 161	Cell and Molecular Biology	3
PSL 250	Introductory Physiology	4
PSL 310	Physiology for Pre-Health Professionals	4
2. Complete 9 credits from the following courses:
 

BE 444	Biosensors for Medical Diagnostics	3
ECE 445	Biomedical Instrumentation	3
ECE 446	Biomedical Signal Processing	3
ECE 447	Introduction to Biomedical Imaging	3
ECE 448	Modeling and Analysis of Bioelectrical Systems	3
ECE 449	Fundamentals of Acoustics	3

Students may enroll in 3 or 4 credits of ECE 490 or 491 with biomedical engineering content as approved by the student's advisor for partial fulfillment of this requirement.

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### Digital Systems and Internet of Things

This concentration is for students interested in graduate work or employment in the world of digital hardware, software and systems within the internet of things (IoT) industry. To earn a Bachelor of Science degree in Electrical Engineering with a Digital Systems and IoT concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. Complete at least four courses from the following:	
CSE 231 Introduction to Programming I	4
ECE 411 Electronic Design Automation	4
ECE 430 Embedded Cyber-Physical Systems	4
ECE 431 Smart Sensors Systems	3
ECE 442 Introduction to Communication Networks	3
ECE 456 Introduction to Communication and Network Security	3
ECE 466 Digital Signal Processing	3

### Electromagnetics, Acoustics and Optics

This concentration is for students interested in graduate work or employment in areas related to electromagnetics, acoustics and optics. To earn a Bachelor of Science degree in Electrical Engineering with an EM, Acoustics and Optics concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. Complete at least four courses from the following:	
ECE 405 Electromagnetic Fields and Waves II	4
ECE 407 Electromagnetic Compatibility	4
ECE 447 Introduction to Biomedical Imaging	3
ECE 449 Fundamentals of Acoustics	3
ECE 476 Electro-Optics 4	

### Radio Frequency and Wireless Technologies

This concentration is for students interested in radio frequency technologies and the theories and principles of electronic communication and networking for graduate work or employment in areas related to wireless communication. To earn a Bachelor of Science degree in Electrical Engineering with an RF and Wireless concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. Completion at least four courses from the following:	
ECE 404 Radio Frequency Electronic Circuits	4
ECE 405 Electromagnetic Fields and Waves II	4
ECE 407 Electromagnetic Compatibility	4
ECE 442 Introduction to Communication Networks	3
ECE 457 Communication Systems	3

### Robotics and Automation

This concentration is for students interested in graduate work or employment in robotics or automation areas. To earn a Bachelor of Science degree in Electrical Engineering with a robotics and automation concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. The following course:	
ECE 417 Robotics	4
2. Complete 9 credits from the following:	
ECE 415 Computer Aided Manufacturing	3
ECE 416 Digital Control 3	
ECE 430 Embedded Cyber-Physical Systems	4
ECE 431 Smart Sensors Systems	3
ECE 434 Autonomous Vehicles	3
ECE 466 Digital Signal Processing	3

### Microelectronics

This concentration is for students interested in graduate work in electronic materials, devices or circuits or employment in the semiconductor industry. To earn a Bachelor of Science degree in Electrical Engineering with a Microelectronics concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. Complete at least four courses from the following:	
ECE 404 Radio Frequency Electronic Circuits	4
ECE 410 VLSI Design	4
ECE 425 Solid State Power Conversion	3
ECE 476 Electro-Optics	4
ECE 477 Microelectronic Fabrication	3

### Smart Devices

This concentration is for students interested in the design and implementation of smart devices and systems for graduate work or employment in consumer electronics and wearables fields. To earn a Bachelor of Science degree in Electrical Engineering with a Smart Devices concentration, students must complete requirements 1., 2., and 3. above and the following:

	CREDITS
1. Complete at least four courses from the following:	
ECE 410 VLSI Design	4
ECE 411 Electronic Design Automation	4
ECE 416 Digital Control	3
ECE 431 Smart Sensors Systems	3
ECE 445 Biomedical Instrumentation	3
ECE 477 Microelectronic Fabrication	3

## GRADUATE STUDY

The Department of Electrical and Computer Engineering offers programs leading to the Master of Science and Doctor of Philosophy degrees. Graduate study is available in research areas such as: computer engineering including computer architecture, computer networks, and VLSI/microelectronics; electrosiences including electromagnetics, electronic materials and devices, and non-destructive evaluation; systems including control and robotics, and power as well as systems including signal processing, communications, and biomedical engineering. An interdisciplinary approach marks many of the research projects and helps prepare students for leadership roles in industrial or academic research. A Graduate Certificate in Secure and Connected Cyber-Physical Systems and a Graduate Certificate in Semiconductor Manufacturing, Processing, and Devices are also available..

### Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

### Admission

Applicants for admission should possess a Bachelor of Science degree in electrical engineering or a related field such as physics, mathematics, or computer science, and should have a grade-point average that would indicate success in graduate study.

Students who are admitted without a Bachelor of Science degree in electrical engineering may be required to complete collateral courses.

International applicants are required to submit Graduate Record Examination General Test scores.

### Requirements for the Master of Science Degree in Electrical and Computer Engineering

The student must complete a total of 30 credits under either Plan A (with thesis) or Plan B (without thesis) and meet the requirements specified below:

	CREDITS
<b>Requirements for Both Plan A and Plan B:</b>	
1. <b>Core Courses.</b> Complete a minimum of four Electrical and Computer Engineering courses at the 800 or 900-level totaling at least 12 credits. Two of the courses must be selected from the following:	
ECE 820 Advanced Computer Architecture	3
ECE 821 Advanced Power Electronics and Applications	3
ECE 830 Embedded Cyber-Physical Systems	3

## COLLEGE OF ENGINEERING

- |         |  |   |
|---------|--|---|
| ECE 835 | Advanced Electromagnetic Fields and Waves I    | 3 |
| ECE 842 | Performance Modeling of Communication Networks | 3 |
| ECE 851 | Linear Systems and Control                     | 3 |
| ECE 863 | Analysis of Stochastic Systems                 | 3 |
| ECE 874 | Physical Electronics                           | 3 |
- Electrical and Computer Engineering 801 cannot be used to fulfill this requirement
2. Completion of supporting course work outside the department and college at the 400-level and above chosen in consultation with the student's academic advisor. Plan A students must have at least 20 credits at the 800-level or above and Plan B students must have 18 credits at the 800-level or above.
  3. **Seminar Requirement.** First-year graduate students are required to attend seven seminars from the graduate seminar series.

### **Additional Requirements for Plan A**

1. Completion of at least 4 credits of ECE 899 Master's Thesis Research, and no more than 8 credits.
2. Pass an oral examination in defense of the thesis.

### **Additional Requirements for Plan B**

1. Completion of a final examination or evaluation.

## **Doctor of Philosophy**

### **Admission**

International applicants are required to submit Graduate Record Examination General Test scores.

### **Requirements for the Doctor of Philosophy Degree in Electrical and Computer Engineering**

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified by their guidance committees.

1. The doctoral program must include a minimum of 36 credits, in addition to 24 credits of Electrical and Computer Engineering 999.
2. No 800-900 level independent study credits taken beyond the bachelor's degree may be counted towards the doctoral degree.
3. A minimum of 3 credits must be taken outside of the College of Engineering in disciplinary areas such as mathematics, statistics, or physics.
4. All courses that are used to satisfy the requirements for the degree must have been completed under the numerical grading system.
5. Students may request up to 3 credits of master's thesis research be applied towards this requirement.
6. First year graduate students are required to attend seven seminars from the graduate seminar series.

### **GRADUATE CERTIFICATE IN SECURED AND CONNECTED CYBER-PHYSICAL SYSTEMS**

The Graduate Certificate in Secured and Connected Cyber-Physical Systems is intended for students with interest in the modeling, design, and analysis of secure and networked cyber-physical systems (CPS). The certificate prepares students for both research work as well for jobs in government and industry in secure and connected CPS, which are growing rapidly.

### **Requirements for the Graduate Certificate in Secured and Connected Cyber-Physical Systems**

CREDITS

Students must complete all of the following courses (9 credits):

ECE 816	Cryptography and Network Security	3
ECE 830	Embedded Cyber-Physical Systems	3
ECE 842	Performance Modeling of Communication Networks	3

Students must have a minimum 3.00 grade-point average over the courses applied to the certificate for it to be awarded.

### **GRADUATE CERTIFICATE IN SEMICONDUCTOR MANUFACTURING, PROCESSING, AND DEVICES**

The Graduate Certificate in Semiconductor Manufacturing, Processing, and Devices is designed to provide students with semiconductor research training that will make them more competitive in the field of semiconductor processing and manufacturing.

### **Requirements for the Graduate Certificate in Semiconductor Manufacturing, Processing, and Devices**

Students must complete a minimum of 9 credits from the following courses:

CREDITS

ECE 813	Advanced VLSI Design	3
ECE 832	Analog Integrated Circuit Design	3
ECE 850	Electrodynamics of Plasmas	3
ECE 870	Introduction to Micro-Electro-Mechanical Systems	3
ECE 871	Micro-electro-mechanical Systems Fabrication	3
ECE 874	Physical Electronics	3
ECE 875	Electronic Devices	3
ECE 877	Cleanroom Procedures	3
ECE 931C	Properties of Semiconductors	3
ECE 989	Advanced Topics in Plasma	3

## DEPARTMENT of MECHANICAL ENGINEERING

*Minami Yoda, Chairperson*

### **UNDERGRADUATE PROGRAMS**

Mechanical engineering is a diverse profession that relies on fundamental science principles to conceive, design, and manufacture everything from miniaturized individual parts (e.g. biosensors, printer nozzles, micro-reactors, electronic coolers) to large complex systems and devices (e.g., rocket propulsion, jet engines, robotic tools, wind turbines, automobiles, water purification, energy storage). Mechanical engineers concentrate/focus on devices and systems that alter, transfer, transform, and utilize energy forms that cause motion. The mechanical engineering practitioner requires a broad range of skills and knowledge. The Department of Mechanical Engineering provides a curriculum that intertwines a foundation in mathematics and engineering science with creativity and innovation in design and fabrication. Students learn the skills to develop ideas from concept to product. The program integrates individual mastery of these subjects with teamwork-based solutions to open-ended design problems



## COLLEGE OF ENGINEERING

and practical engineering experiences. Along with the required courses, optional concentrations are available for students to focus their program of study within a particular area of interest, as well as opportunities to study abroad.

### MECHANICAL ENGINEERING

Mechanical engineering is a diverse profession that relies on fundamental science principles to conceive, design, and manufacture everything from miniaturized individual parts such as biosensors, printer nozzles, and micro-reactors to large complex systems and devices such as rocket propulsion, jet engines, robotic tools, wind turbines, and automobiles. Mechanical engineers are concerned with conceiving, designing, manufacturing, testing and marketing devices and systems that alter, transfer, transform and utilize energy forms that cause motion. In order to be accomplished in the mechanical engineering profession, a broad range of skills and knowledge are required.

The Department of Mechanical Engineering provides a curriculum that intertwines a foundation in mathematics and engineering science with creativity and innovation in design. Students learn the skills to develop ideas from concept to product. The program integrates individual mastery of these subjects with teamwork-based solutions to open-ended design problems and practical engineering experiences. Along with the required courses, optional concentrations are available for students to focus their program of study within a particular area of interest.

The design program is a core pillar of the undergraduate curriculum that combines core instruction in design with hands-on experiences in design-build-test projects. A sequence of four design intensive courses culminates in a capstone course, underpinned by industrially-sponsored projects. Industrial sponsorship for the capstone design experience is strong. Over the last ten years, 130 companies, many from within the state, have sponsored over 325 capstone design projects. In addition to industrially-motivated projects, students have the option to participate in humanitarian projects. Students present their work on Design Day, the last day of classes in fall and spring.

The Department has a long-established study abroad program in Germany (RWTH in Aachen) and study abroad programs in France (École Catholique d'Arts et Métiers), the United Kingdom (University of Edinburgh), Korea (Korea University) and Denmark (Technical University of Denmark). The program also attracts a diverse group of international students to study with us. Included in the variety of activities open to students is the cooperative education program, in which a student may participate after his/her freshman year.

The Bachelor of Science Degree program in Mechanical Engineering is accredited by the Engineering Accreditation Commission of ABET, [www.abet.org](http://www.abet.org).

#### Requirements for the Bachelor of Science Degree in Mechanical Engineering

1. The University requirements for bachelor's degrees as described in the *Undergraduate Education* section of this catalog; 128 credits, including general elective credits, are required for the Bachelor of Science degree in Mechanical Engineering.

The University's Tier II writing requirement for the Mechanical Engineering major is met by completing Mechanical Engineering 332, 412, and 481. Those courses are referenced in item 3. b. (1) below.

Students who are enrolled in the College of Engineering may complete the alternative track to Integrative Studies in Biological and Physical Sciences that is described in item 1. under the heading *Graduation Requirements for All Majors* in the *College* statement. Certain courses referenced in requirement 3. below may be used to satisfy the alternative track.

2. The requirements of the College of Engineering for the Bachelor of Science degree.

The credits earned in certain courses referenced in requirement 3. below may be counted toward College requirements as appropriate.

3. The following requirements for the major:

	CREDITS
a. All of the following courses outside the Department of Mechanical Engineering (13 credits):	
CE 221 Statics	3
CEM 161 Chemistry Laboratory I	1
ECE 345 Electronic Instrumentation and Systems	3
MSE 250 Materials Science and Engineering	3
STT 351 Probability and Statistics for Engineering	3
b. All of the following courses in the Department of Mechanical Engineering (40 credits):	
ME 222 Mechanics of Deformable Solids	3
ME 280 Graphic Communications	2
ME 201 Thermodynamics	3
ME 300 Professional Issues in Mechanical Engineering	1
ME 333 Fluid Mechanics	3
ME 333L Fluid Mechanics Laboratory	1
ME 361 Dynamics	3
ME 370 Mechanical Design and Manufacturing I	3
ME 391 Mechanical Engineering Analysis	3
ME 410 Heat Transfer	3
ME 412 Heat Transfer Laboratory	2
ME 452 Control Systems	3
ME 452L Vibrations and Controls Laboratory	1
ME 461 Mechanical Vibrations	3
ME 470 Mechanical Design and Manufacturing II	3
ME 481 Mechanical Engineering Design Projects	3
c. Senior Electives (a minimum of 9 credits):	
ME 413 Cryogenic-Thermal Systems	3
ME 414 Mechanical Design of Cryogenic Systems	3
ME 416 Computer Assisted Design of Thermal Systems	3
ME 417 Design of Alternative Energy Systems	3
ME 422 Introduction to Combustion	3
ME 423 Intermediate Mechanics of Deformable Solids	3
ME 425 Experimental Mechanics	3
ME 426 Introduction to Composite Materials	3
ME 433 Introduction to Computational Fluid Dynamics	3
ME 440 Aerospace Propulsion	3
ME 441 Aerodynamics and Aircraft Performance	3
ME 442 Turbomachinery	3
ME 444 Automotive Engines	3
ME 445 Automotive Powertrain Design	3
ME 456 Mechatronic System Design	3
ME 464 Intermediate Dynamics	3
ME 465 Computer Aided Optimal Design	3
ME 475 Computer Aided Design of Structures	3
ME 477 Manufacturing Processes	3
ME 478 Product Development	3
ME 490 Independent Study in Mechanical Engineering	1 to 3
ME 491 Selected Topics in Mechanical Engineering	1 to 4
ME 494 Biofluid Mechanics and Heat Transfer	3
ME 495 Tissue Mechanics	3
ME 496 Biomechanical Analysis of Human Movement	3
ME 497 Biomechanical Design in Product Development	3
d. Design-intensive Senior Electives (a minimum of 3 credits):	
ME 414 Mechanical Design of Cryogenic Systems	3
ME 416 Computer Assisted Design of Thermal Systems	3
ME 417 Design of Alternative Energy Systems	3
ME 442 Turbomachinery	3
ME 445 Automotive Powertrain Design	3
ME 456 Mechatronic System Design	3
ME 465 Computer Aided Optimal Design	3
ME 475 Computer Aided Design of Structures	3

## COLLEGE OF ENGINEERING

ME 478	Product Development	3
ME 497	Biomechanical Design in Product Development	3
Courses used to fulfill item 3. c. may not be used to fulfill item 3. d.		

### Concentration in Aerospace Engineering

A concentration in Aerospace Engineering is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in Aerospace Engineering may require more than 128 credits. The concentration will be noted on the student's transcript.

#### Aerospace Engineering

A mechanical engineering degree with the aerospace engineering concentration recognizes the expertise of students in subjects related to aerospace applications and to the aerospace industry, which provides many career opportunities for mechanical engineering graduates. Students who meet the requirements of this concentration will have expertise in aerodynamics, propulsion and structures, supplemented by other strengths in the core Mechanical Engineering degree program. To complete a Bachelor of Science degree in mechanical engineering with an aerospace engineering concentration, students must complete the requirements for the B.S. degree, including the following:

		CREDITS
Both of the following courses (6 credits):		
ME 440	Aerospace Propulsion	3
ME 441	Aerodynamics and Aircraft Performance	3
One of the following courses (3 credits):		
ME 423	Intermediate Mechanics of Deformable Solids	3
ME 426	Introduction to Composite Materials	3
ME 456	Mechatronic System Design	3
ME 475	Computer Aided Design of Structures	3
One of the following courses (3 credits):		
ME 422	Introduction to Combustion	3
ME 433	Introduction to Computational Fluid Dynamics	3
ME 442	Turbomachinery	3

### Concentration in Automotive Powertrain

A concentration in Automotive Powertrain is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in automotive powertrain may require more than 128 credits. The concentration will be noted on the student's transcript.

#### Automotive Powertrain

To earn a Bachelor of Science degree in Mechanical Engineering with an automotive powertrain concentration, students must complete the requirements for the B.S. degree, including the following:

		CREDITS
All of the following courses (9 credits):		
ME 422	Introduction to Combustion	3
ME 444	Automotive Engines	3
ME 445	Automotive Powertrain Design	3
One of the following courses (3 credits):		
ME 433	Introduction to Computational Fluid Dynamics	3
ME 442	Turbomachinery	3

### Concentration in Biomedical Engineering

A concentration in Biomedical Engineering is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in biomedical engineering may require more

than 128 credits. The concentration will be noted on the student's transcript.

#### Biomedical Engineering

To earn a Bachelor of Science degree in Mechanical Engineering with a biomedical engineering concentration, students must the requirements for the B.S. degree, including the following:

		CREDITS
Both of the following courses (7 credits):		
BS 161	Cell and Molecular Biology	3
PSL 250	Introductory Physiology	4
Nine credits from the following courses:		
BE 444	Biosensors for Medical Diagnostics	3
ECE 445	Biomedical Instrumentation	3
ME 494	Biofluid Mechanics and Heat Transfer	3
ME 495	Tissue Mechanics	3
ME 496	Biomechanical Analysis of Human Movement	3
ME 497	Biomechanical Design in Product Development	3
MSE 425	Biomaterials and Biocompatibility	3
Students who select BE 444, ECE 445, or MSE 425 may request to apply these course credits towards fulfillment of the Mechanical Engineering Major Senior-Elective requirement (item 3. c. above).		

### Concentration in Computational Design

A concentration in Computational Design is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in computational design may require more than 128 credits. The concentration will be noted on the student's transcript.

#### Computational Design

To earn a Bachelor of Science degree in Mechanical Engineering with a computational design concentration, students must the requirements for the B.S. degree, including the following:

		CREDITS
All of the following courses (9 credits):		
ME 416	Computer Assisted Design of Thermal Systems	3
ME 417	Design of Alternative Energy Systems	3
ME 433	Introduction to Computational Fluid Dynamics	3
ME 445	Automotive Powertrain Design	3
ME 456	Mechatronic System Design	3
ME 465	Computer Aided Optimal Design	3
ME 475	Computer Aided Design of Structures	3

### Concentration in Cryogenic Engineering

A concentration in Cryogenic Engineering is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in Cryogenic Engineering may require more than 128 credits. The concentration will be noted on the student's transcript.

#### Cryogenic Engineering

A mechanical engineering degree with the cryogenic engineering concentration recognizes the expertise of students in thermal and mechanical analysis and design techniques as applied to cryogenic engineering applications. To complete a Bachelor of Science degree in mechanical engineering with a cryogenic engineering concentration, students must complete the requirements for the B.S. degree, including the following:

		CREDITS
All of the following courses (12 credits):		
ME 413	Cryogenic-Thermal Systems	3
ME 414	Mechanical Design of Cryogenic Systems	3
ME 416	Computer Assisted Design of Thermal Systems	3
ME 442	Turbomachinery	3

## COLLEGE OF ENGINEERING

### Concentration in Energy

A concentration in Energy is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in energy may require more than 128 credits. The concentration will be noted on the student's transcript.

#### Energy

To earn a Bachelor of Science degree in Mechanical Engineering with an energy concentration, students must complete the requirements for the B.S. degree, including the following:

	CREDITS
Both of the following courses (6 credits):	
ME 416 Computer Assisted Design of Thermal Systems	3
ME 417 Design of Alternative Energy Systems	3
Two of the following courses (6 credits):	
ME 422 Introduction to Combustion	3
ME 440 Aerospace Propulsion	3
ME 442 Turbomachinery	3
ME 444 Automotive Engines	3

### Concentration in Engineering Mechanics

A concentration in Engineering Mechanics is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in engineering mechanics may require more than 128 credits. The concentration will be noted on the student's transcript.

#### Engineering Mechanics

To earn a Bachelor of Science degree in Mechanical Engineering with a engineering mechanics concentration, students must complete the requirements for the B.S. degree, including the following:

	CREDITS
The following courses (12 credits):	
ME 423 Intermediate Mechanics of Deformable Solids	3
ME 425 Experimental Mechanics	3
ME 464 Intermediate Dynamics	3
ME 475 Computer Aided Design of Structures	3

### Concentration in Manufacturing Engineering

A concentration in Manufacturing Engineering is available to, but not required of, any student enrolled in the Bachelor of Science degree in Mechanical Engineering. Completing the Bachelor of Science degree in Mechanical Engineering with a concentration in manufacturing engineering may require more than 128 credits. The concentration will be noted on the student's transcript.

#### Manufacturing Engineering

To earn a Bachelor of Science degree in Mechanical Engineering with a manufacturing engineering concentration, students must the requirements for the B.S. degree, including the following:

	CREDITS
All of the following courses (7 credits):	
ME 372 Machine Tool Laboratory	1
ME 477 Manufacturing Processes	3
ME 478 Product Development	3
One of the following courses (3 credits):	
CHE 472 Polymeric Composite Materials Processing	3
ECE 415 Computer Aided Manufacturing	3
MSE 426 Introduction to Composite Materials	3
One of the following courses (3 credits):	
ACC 230 Survey of Accounting Concepts	3
EC 201 Introduction to Microeconomics	3

Students who select CHE 472, ECE 415, or MSE 426 may request to apply these course credits towards fulfillment of the Mechanical Engineering Major Senior-Elective requirement (item 3. c. above).

## GRADUATE STUDY

The Department of Mechanical Engineering offers programs leading to Master of Science and Doctor of Philosophy degrees, both in mechanical engineering and engineering mechanics. An individualized plan of study can be designed from a wide range of courses and research experiences to suit the professional aspirations of graduate students. A plan of study typically includes courses within and external to the department. The department offers research experiences in four broad areas: Fluid Thermal Science and Engineering; Biomechanics; Dynamic Systems and Control; and Solid Mechanics, Design, and Manufacturing. The research opportunities are diverse and include working closely with an individual faculty member and/or as part of a team in a large interdisciplinary research center. Graduate students are expected to enroll in courses that promote rapid professional growth as well as engage in research that leads to new knowledge creation that pushes the boundaries of science and engineering.

### ENGINEERING MECHANICS

#### Master of Science

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### Admission

The department welcomes applications from students who possess a bachelor's degree in a related engineering or science discipline.

Students who are admitted to the master's program with a degree in a discipline other than engineering mechanics and who have not completed Mechanical Engineering 221, 222, 361, and 423 or equivalent courses may be admitted with provisional status. Such students will be required to demonstrate proficiency in the material in the courses referenced above, either by completing each of those courses with a grade of at least 3.0 or by passing an examination on the material in those courses sanctioned by the department Graduate Studies Committee. Of the courses referenced above, only Mechanical Engineering 423 may be counted toward the requirements for the master's degree.

### Requirements for the Master of Science Degree in Engineering Mechanics

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis) and must meet the requirements specified below:

#### Requirements for Both Plan A and Plan B:

1. The following core courses in engineering mechanics: Mechanical Engineering 825 or 861, 820, and 821.
2. At least one of the following core courses in mechanical engineering: Materials Science and Engineering 851, 855, 862, or 865.
3. At least one credit of Materials Science and Engineering 885.

## COLLEGE OF ENGINEERING

- At least one course in mathematics or statistics at the 400-level or above approved by the student's academic advisor.

### **Doctor of Philosophy**

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### **Admission**

An applicant for admission must identify at least one prospective faculty advisor that they would like to direct their program of study. Admission to the Ph.D. program is contingent on a faculty advisor accepting the student as an advisee.

#### **Requirements for the Doctor of Philosophy Degree in Engineering Mechanics**

The student must complete:

- At least one of the following core courses in materials science and engineering: Materials Science and Engineering 851, 855, 862, or 865.
- At least one course in mathematics or statistics at the 400-level or above.

These requirements are waived for those students who completed equivalent courses prior to enrolling in the doctoral program.

## **MECHANICAL ENGINEERING**

### **Master of Science**

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### **Admission**

An applicant should possess a bachelor's degree in mechanical engineering or a related field.

The applicant must submit scores from the Graduate Record Examination General Test.

#### **Requirements for the Master of Science Degree in Mechanical Engineering**

The student must complete a total of 30 credits for the degree under either Plan A (with thesis) or Plan B (without thesis) and meet the requirements specified below. A maximum of 9 credits may be at the 400-level. A maximum of 4 credits may be taken from ME 490 and ME 990 combined.

##### **Requirements for Both Plan A and Plan B:**

The student must:

- Complete one course from each of the following areas:

##### **Fluid-Thermal Science and Engineering**

ME 810	Advanced Classical Thermodynamics	3
ME 812	Conductive Heat Transfer	3
ME 814	Convective Heat Transfer	3
ME 819	Combustion	3
ME 830	Fluid Mechanics I	3
ME 840	Computational Fluid Dynamics and Heat Transfer	3
ME 842	Advanced Turbomachinery	3
ME 872	Finite Element Method	3

##### **Dynamic Systems and Control**

ECE 851	Linear Systems and Control	3
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ME 860	Theory of Vibrations	3
ME 861	Advanced Dynamics	3
ME 891	Selected Topics in Mechanical Engineering	1 to 4

The topic for ME 891 must be approved by the student's guidance committee.

##### **Solid Mechanics, Design, and Manufacturing and Biomechanics**

ME 820	Continuum Mechanics	3
ME 821	Linear Elasticity	3
ME 826	Laminated Composite Materials	3
ME 872	Finite Element Method	3
ME 891	Selected Topics in Mechanical Engineering	1 to 4

The topic for ME 891 must be approved by the student's guidance committee.

##### **Additional Requirements for Plan A:**

The student must:

- Complete 21 credits in courses at the 800–900 level including at least 6, but not more than 8, credits in Mechanical Engineering 899.
- Submit a brief thesis proposal for approval by the student's academic advisor early in the student's program of study.
- Pass an oral examination in defense of the thesis.

##### **Additional Requirements for Plan B:**

- Complete 21 credits in courses at the 800–900 level.
- Complete a final examination or evaluation.

### **Doctor of Philosophy**

In addition to meeting the requirements of the university and of the College of Engineering, students must meet the requirements specified below.

#### **Admission**

The applicant must submit scores from the Graduate Record Examination General Test.

#### **Requirements for the Doctor of Philosophy Degree in Mechanical Engineering**

In addition to meeting the requirements of the university and the College of Engineering, students must meet the requirements specified by their guidance committees.